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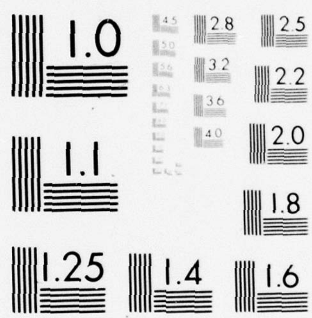

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COMPRESSOR BLADE MANUFACTURE BY ELECTROCHEMICAL MACHINING

ADVANCED TURBINE ENGINE GAS GENERATOR

GENERAL ELECTRIC COMPANY
AIRCRAFT ENGINE GROUP
CINCINNATI, OHIO 45215

August 1977

TECHNICAL REPORT AFAPL-TR-77-33
Final Report for Period December 1973 - March 1977

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This technical report has been reviewed and is approved for publication.

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Project Engineer/Scientist

FOR THE COMMANDER

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Compressor blades for the ATEGG GE14 engine were manufactured using electrochemical machining to form the airfoils. Elaborate dimensional inspections were performed on the as-machined surfaces. The blades were tested for frequency, nodal patterns, and fatigue strength and were compared to control blades made by conventional methods.

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FOREWORD

The work of this study was performed by the General Electric Company's Aircraft Engine Group, Cincinnati, Ohio 45215, under Contract F33657-72-C-0206 with the USAF Aero Propulsion Laboratory (TBP), Wright-Patterson AF Base, Dayton, Ohio 45433. The AF Project Monitor was Raymond N. Leo.

The technical effort was begun in December 1973 and extended through March 1977.

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SECTION I

INTRODUCTION

Electrochemical machining, ECM, is a process which removes material from an electrically conductive workpiece by electrolytic action and can be likened to plating in reverse. Metal removal is accomplished by means of anodic dissolution produced by the passage of a machining current through a flowing electrolyte which separates the electrode from the workpiece. The workpiece and electrode tool are connected to a d.c. power supply with the former being positively charged and the latter, negative. When a electrolyte (usually a saline solution) is pumped through the cutting gap and a current is flowing, metal is dissolved from the workpiece and into the electrolyte while the electrode tool is advanced toward the workpiece at a constant rate.

The cutting gap between the electrode tool and the workpiece is controlled by the magnitude of the voltage applied, and can be varied from 0.001-inch to 0.030-inch (practical range). The smaller the gap, the more closely the workpiece will be to a mirror image of the electrode tool. The most commonly used gaps are from 0.005-inch to 0.010-inch, which is close enough to insure a practical reproduction of the tool geometry in the workpiece.

The entire electrolytic cell is enclosed in a flow chamber or box, suitably sealed to permit the tool to be fed into the workpiece and at the same time, prevent leakage of the electrolyte. Normally, this flow box is designed so as to provide flow passages to and from the working gap. This gives greater control over the fluid flow which can be used to great advantage during Electromechical Machining.

The advantages of the ECM process include potential cost reductions for typical blade materials, the production of geometrically more consistent parts and resulting blade dynamic characteristics which should be more consistent. Further, blades can be made from a wider variety of materials, since ECM is fairly insensitive to the material being machined.

A task of the ECM manufacture of compressor blades was offered as Option IV to the FY 74/75 modification of ATEGG contract F33657-72-C-0206. The option was exercised in December 1973 and the work began early in 1974. The work effort is described in Paragraph 9.4 of the contract Statement of Work. Blade construction by ECM methods was to provide a full set of blades for three GE14 compressor stages, as well as a quarter set of blades for structure test comparisons with a quarter set of conventionally manufactured blades for each stage. A graphical summary of the program is presented in Figure 1.

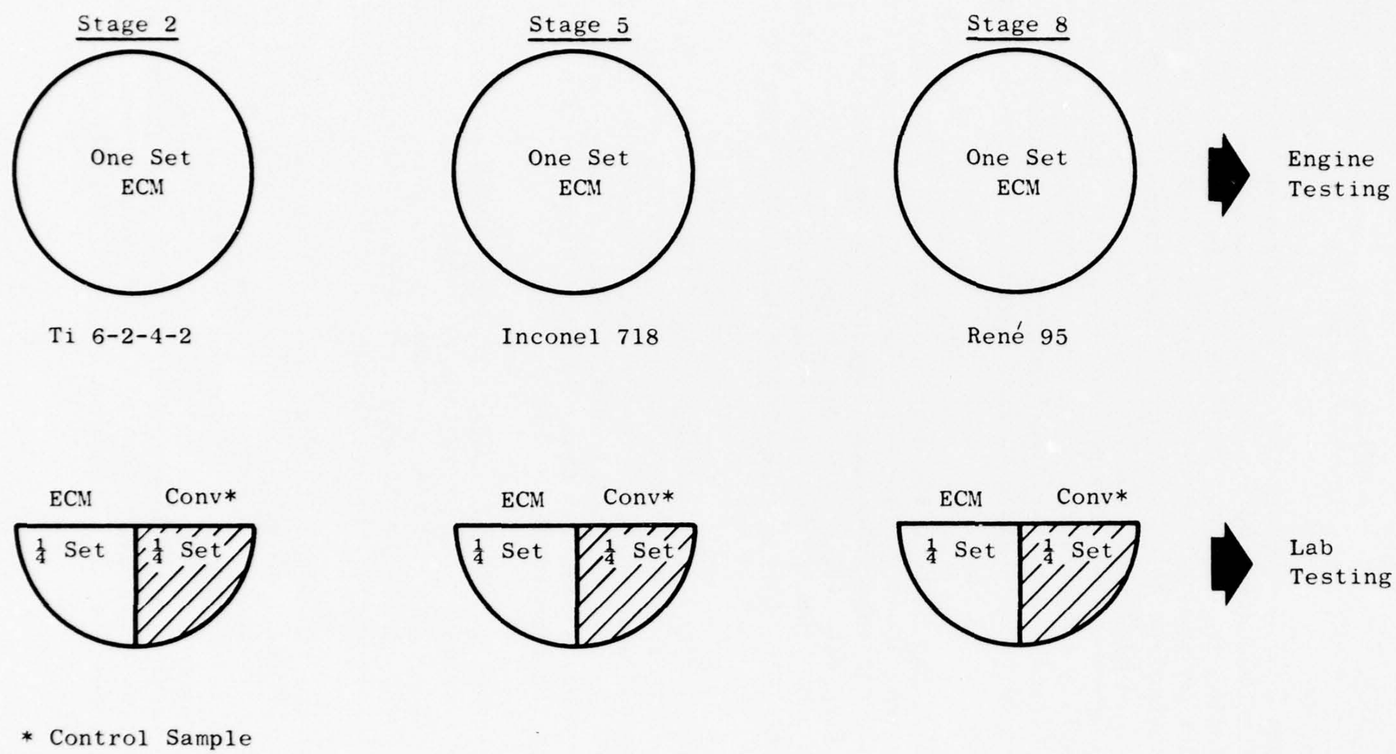


Figure 1. ATEGG Option Program.

Work to be accomplished included the following tasks:

1) Manufacture by means of electrochemical machining (ECM) of one and a quarter sets of compressor rotor blades for each of three stages of the GE14/J1B3 compressor.

2) Manufacture by means of conventional machining one-quarter set of the same stages for use as a control sample.

3) Perform a detailed geometry investigation of manufacture results of ECM to assess dimensional consistency.

4) Determination of resonant frequency and nodal pattern of each of the three stages of blades (one-quarter set of each machining method).

5) Flexural fatigue strength testing of each three stages of blades (one-quarter set of each machining method).

6) Determination of the relative cost and delivery of blades made by the two methods.

7) Manufacture of about 30 stage-5 blades by machining the dovetail first as would be done in a production process.

Considerable technical difficulty was encountered in the initial production of ECM blades at both the vendors involved in the program which stretched the manufacture of the Stage 2 and 5 blades into mid 1975. Also, difficulty with the powder metal material for the Stage 8 blades was encountered: A lot was scrapped in July of 1974 and the replacement lot delivered in October of 1974 was found to be partly defective. These material problems contributed to a series of delays at the vendor which stretched completion of only a partial set of R95 ECM blades into the last quarter of 1975. A substitute task for the remaining R95 Stage 8 blades was negotiated with the Air Force in the first quarter of 1976 (item 7 in the task list above). The program was completed in April of 1976.

SECTION II

SUMMARY

Blades were built using ECM and conventional machining methods. Stages 2, 5, and 8 of the GE14/J1B3 compressor were chosen for this task. They represent different sizes, types of blades, and materials. Stage 2 was made from titanium 6-2-4-2; Stage 5 was made from Inconel 718; and, Stage 8 was made from René 95. These materials present a wide variety of machining difficulty. All materials were originally intended to be cast and wrought (C&W) as is usual practice in airfoil manufacture. In the case of the R95 material for the Stage 8 ECM blades, powder metal (PM) material was used as most representative of a low cost source in keeping with the intent of the study. Both cost and delivery advantages over cast and wrought material were promised for the lot of approximately 100 R95 slugs required for ECM manufacturing when material was ordered early in 1974. Each of the blades generated in this program is shown in Figure 2.

The program proved that blades can be made from a variety of materials and in quantity using a quasi-production-type ECM process for generating the airfoil and adjacent flowpath surfaces. The blades produced by ECM in this program show excellent geometric characteristics relative to blade shape and dimensional consistency. Leading and trailing edge contours can be held well within existing tolerance bonds. Standard deviations on blade chord, maximum thickness, leading edge thickness, and trailing edge thickness are much smaller than standard airfoil tolerances on these variables. Available data on a production blade process indicate that the values shown in a later table for ECM manufacture represent about a 50% improvement in dimensional control over conventional methods.

The ECM vendors were not required to handwork in airfoil and adjacent flowpath surfaces; these surfaces were to be as-machined. Only the vendor for the Stage 5 blades complied with this restriction. Since hardwork introduces uncontrolled variability, only the Stage 5 blades are truly representative of the ECM process in a geometric and dynamic sense. For this reason, only the Stage 5 geometry data are included. Section IVA contains the detailed data for reference.

There was found to be no clear cut advantage of ECM's airfoils over airfoils produced by conventional means with regard to natural frequencies and nodal patterns. Stage 5, however, with as-ECM'd surfaces, exhibited consistently better frequency scatter and standard deviation. The variability produced by hand rework on Stages 2 and 8 may have distorted the results.

As-ECM'd blades with peening showed several advantages over conventional blades in areas related to fatigue strength. The standard deviation was found to be smaller than for conventionally made blades. Hence, the average fatigue strength was diminished less for as-ECM'd blades than for conventional blades to obtain the design allowable levels. The fatigue test results are summarized in Table 1, where the 90% confidence column represents

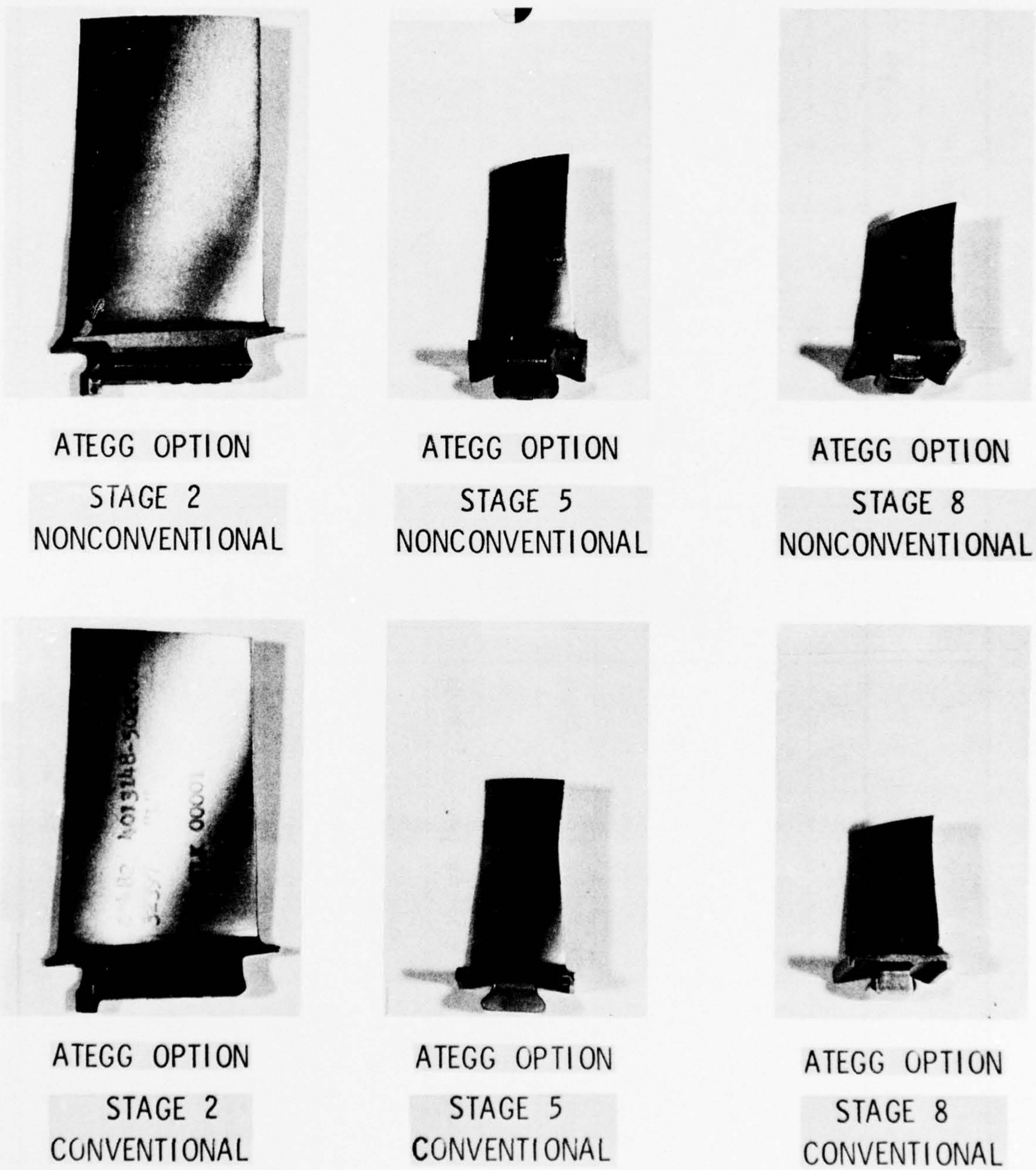


Figure 2. GE14 Compressor Blades.

Table 1. Summary of Fatigue Results.

Configuration	Material §	Peened ?	Fatigue Strength†		
			Average	Std Dev	90% Confidence
Stage 2 (Conv.)	Ti 6-2-4-2 (C&W)	Yes	141	4.3	124
Stage 2 (ECM)	Ti 6-2-4-2 (C&W)	Yes	145	<1.0	143
Stage 5 (Conv.)	Inconel 718 (C&W)	Yes	142	4.1	126
Stage 5 (ECM)	Inconel 718 (C&W)	No	121	4.4	105
Stage 8 (Conv.)	René 95 (C&W)	Yes	219	4.5	202
Stage 8 (ECM)	René 95 (PM/as-HIP'd)	Yes	207	3.1	195
Stages 7 & 8 (ECM)‡	René 95 (C&W)	Yes	230	1.0	226
Stage 5 (ECM)	René 95 (PM/as-HIP'd)	No	131	4.3	115
Test Specimen (ECM)*	René 95 (C&W)	No	114	-	-
Test Specimen (ECM)*	René 95 (C&W)	Yes	210	-	-
Test Specimen (ECM)*	René 95 (PM/as-HIP'd)	No	124	-	-
Test Specimen (ECM)*	René 95 (PM/as-HIP'd)	Yes	220	-	-

† All values are ksida.

‡ Included to correlate PM & C&W from blade tests. Data from a previous Study.

* Materials data included to correlate effect of peening and C&W and PM.

§ PM is powder metal C&W is cast and wrought.

the useable strength of each blade set. With equivalent material to start, and peening all blades, the ECM process produced blades of higher useable fatigue strength by more than 10%.

A summary of the procurement costs for the program is presented in Table 2. Although these costs are difficult to relate to production cost, it is noteworthy that costs per blade were roughly equivalent, with the relative cost of ECM decreasing with increasing material strength (Stage 8, René 95).

The present program successfully demonstrated ECM manufacture of blades with pre-machined dovetails. This allowed production of a stress-free airfoil with improved fatigue design strength in the peened condition compared to a conventionally produced peened blade. As with the previous ECM blades, dimensional and contour consistency was excellent. This process is believed cost-competitive with conventional processes for current high-strength nickel base alloys and yields high quality blades.

Table 2. Cost Summary

Stage	Conv	ECM
2		
Quality	15	75
Machining Cost, $	4.3K	27.3K
Tooling Cost, $	0	3.6K
Cost/Blade, $	268.00	306.00
5		
Quality	20	102
Machining Cost, $	6.1K	33.7K
Tooling Cost, $	0	3.7K
Cost/Blade, $	288.00	294.00
5 (R95)		
Quality	-	30
Machining Cost, $	-	16.7K
Tooling Cost, $	-	φ
Cost/Blade, $	**	557.90 (375.00)*
8		
Quality	20	100†
Machining Cost, $	7.4K	28.9K
Tooling Cost,$	0	φ
Cost/Blade, $	248.00	289.00

* Based upon a lot size comparable to the other stage lots, the unit cost would reduce to $375.00. Tooling used was stg 5 Znco 718 tooling.

** No conventionally machined R95 stage 5 blades are available for direct comparison.

† The program actually produced 58 pieces at this unit price. Further machining was abondoned due to extensive delays in obtaining the PM Rene 95 Material.

φ Tooling costs not provided by vendor.

SECTION III

BLADE MANUFACTURE

The nonconventional blades all used ECM to generate the airfoil and adjacent flowpath surfaces; the dovetails were all generated subsequently using EDM. The Stage 5 blade airfoil leading and trailing edges were finished entirely by ECM; those on Stages 2 and 8 were routinely hand polished.

The conventionally machined blades were milled and belt polished to final contour.

The vendors for each of the blades are listed in Table 3.

Table 3. Vendor Listing.

Stage	Conventional	Unconventional
2	Jarvis	Metem Corp.
5	Jarvis	Lehr Precision
8	Mal	Metem Corp.

No restrictions were placed on the vendors making the blades by conventional means. The vendors using ECM methods were required to do no hand finishing of airfoil contours -- the flowpath surfaces were to be completely generated by the ECM process. The vendors doing the ECM blades were permitted to generate the dovetail form by use of electrodischarge machining (EDM).

The material used for Stages 2 and 5 was cast and wrought. This was originally the plan for Stage 8 also. However, it was identified part-way through the program that as-HIP'd power metal (PM) René 95 material could be obtained for this stage. The decision was made to go with PM since it represents an additional cost advantage, primarily for ECM blades. When the decision was made to go with PM, it was too late to stop the conventional machining vendor from using cast and wrought material; however, the ECM vendor was redirected to using PM. As will be noted later, this necessitated additional bench testing.

Only the vendor doing the Stage 5 blades by ECM complied with the restriction of no handwork on airfoil surfaces. Handworking produces surface stresses that can significantly affect the base fatigue of a part. Therefore, the ECM Stages 2 and 8 blades (which were both made by the same vendor) had to be glass-bead peened.

A cost summary is shown in Table 2 as it relates to the limited blade procurement for this program. There is difficulty in generating representative data for production quantities for the ECM blades; whereas, the conventional approach (closed die forging or roll forming) has a well-documented cost history. Current equipment limitations in the ECM area, in the field of solid state electronic process parameter controllers, make predictions very subjective. However, our experience on this program allows us to make a very optimistic forecast that blade costs for materials such as René 95 and Inconel 718 will be comparable to those for titanium blades produced conventionally.

The data presented in the subsequent sections illustrate that ECM'd blades are technically equivalent or superior to conventionally made blades. However, the question of economics must be addressed. With current technology, there is no advantage to generating titanium blades by ECM. Conventional methods of forging to size and/or roll forming are clearly superior. Scrap rates are low and die life is high because of relatively easy forming characteristics of titanium alloys. Existing press capacity size is likewise no problem.

The introduction of nickel-base blade materials, especially René 95, swings the balance in favor of ECM. In the case of Inconel 718, there is a slight advantage to ECM; and, in the case of René 95, the scales are tipped completely to ECM's favor. These are necessarily subjective evaluations that should be substantiated by thorough economic analysis.

Many areas of manufacture by ECM require development. Foremost of these is full utilization of solid state low voltage controls for power supplied. This would permit considerable improvement in filtering out noise "dirty extraneous electrics" that confuse present spark detection devices. This feature is critical to process cost control to assure protection of expensively shaped cathodes.

At present, cathode design for the ECM is a process trial and error procedure. However, with full control of all variable process parameters, design of the cathodes becomes predictable. Translation of an airfoil shape to a cathode could then be achieved by numerically controlled machining of this shape much the same as airfoils are now conventionally machined.

No attempt was made during the initial phase of the ECM study to optimize the manufacturing sequence to be cost effective. The program concentrated on the production of a high quality airfoil and, therefore, machined the dovetail last because of concern that the completed dovetail would be damaged when it carried the high current involved in the ECM generation of the airfoil. At the end of this phase of work it was apparent that the processing sequence needed to be changed to make ECM airfoils manufacture cost competitive for high temperature materials. Of the items requiring improvement, only the need to complete all machining of the dovetail and platform underside prior to generation of the airfoil to free the airfoil of fatigue stresses induced while holding the airfoil to machine the dovetail

in the original process was believed a significant difficulty for production manufacturing. The specific problem was the limited shank size available. Further, problems of reliably sealing a charged electrode during the ECM process from the shank area were believed to provide a further barrier. As a result of these questions in the cost effective process, the present program was proposed and accepted by the Air Force to offset the 42 blade short fall in the Stage 8 R95 manufacture.

Construction of a 4 blade pilot lot of Stage 5 airfoils was completed using an ECM process, R95 PM material and with premachined dovetails. With the success of the pilot lot, work was begun to produce the remaining 26 required airfoils.

The work of producing the lot of 30 airfoils was done at Lehr Precision, the vendor where the Stage 5 blades were made by ECM from Inconel 718 material during the original phase of the program. After several approaches were studied for the dovetail first manufacture process, a metal matrix was cast around the finished dovetail to provide a piece for the ECM process which directly resembled the blank before the dovetail was machined. This arrangement isolated the dovetail from the charged electrolyte and provided a sufficient cross section for the high current of the ECM blade processing. The arrangement also provided reliable fixturing surfaces for both the ECM process and the subsequent grinding operations (needed to finish the four sides of the blade platform).

SECTION IV

TESTING AND INSPECTION

A. Dimensional Checks

The Stage 5 ECM'd blades were inspected thoroughly, piece be piece, using inspection gaging built for this specific purpose. Inspection Sections B-B, C-C, D-D, E-E, F-F, G-G, and H-H were used to obtain measurements of airfoil chord, leading edge thickness, maximum thickness, and trailing edge thicknesses. Of interest here was the variation obtained from blade to blade. The blade sections are defined on Figure 3. The measured geometric data for the Stage 5 blade is summarized in Table 4. Included for reference is the tolerance given for production blades made by conventional methods. No measurements were made on the control sets of blades in this study or on the Stages 2 and 8 ECM'd blades, because it was believed that the hand finishing involved resulted in larger tolerances than the production tolerances quoted as a reference.

The detailed part-by-part tabulation of measurement results is presented in Table 5, for the original 120 piece lot of Inco 718 ECM blades.

The R95 Stage 5 ECM blades were inspected at Stations B-B, D-D and F-F and the values of chord, leading edge thickness, maximum thickness and trailing edge thickness were determined. A summary of these variations is included in Table 5. Note that all dimensions are as manufactured, without any hand finishing. Again, airfoil contours and edges were excellent. Leading and trailing edge contours were particularly smooth and consistent.

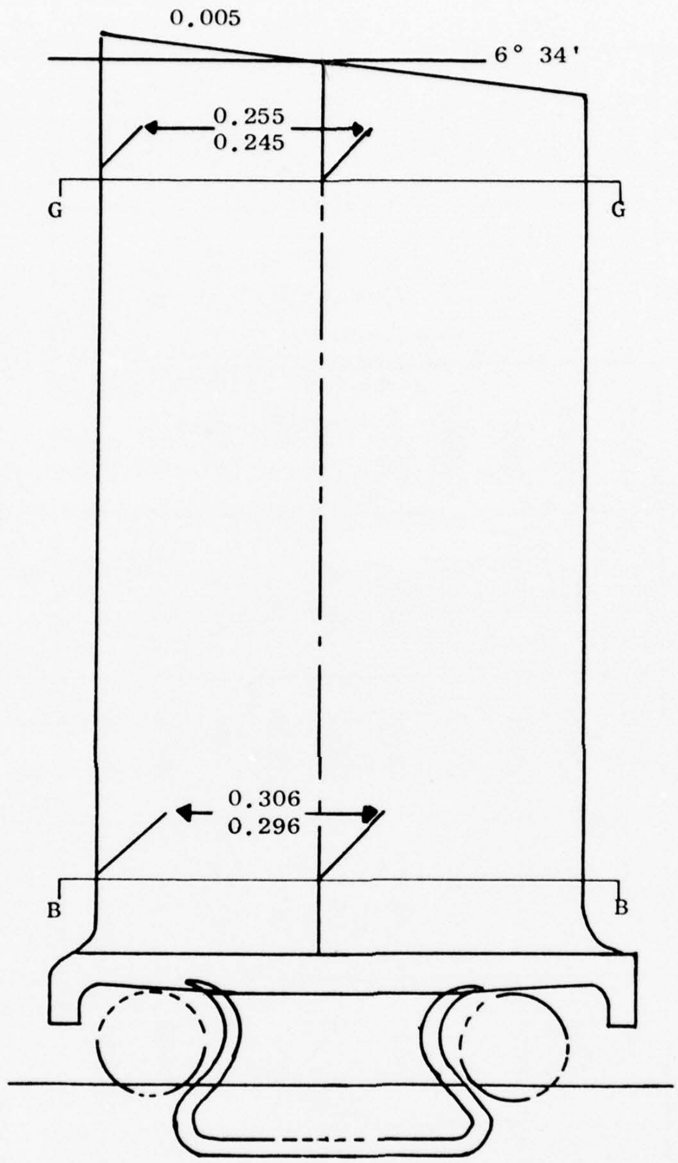
B. Frequencies and Nodal Patterns

One quarter set of each stage and type of manufacture was tested for resonant frequencies and nodal patterns. To accomplish this, the blades were clamped in a fixture simulating the root fixity that exists in an engine and were excited by a variable frequency electromagnetic drive at the individual blade's natural frequencies. Figure 4 represents a typical test setup with a much larger blade than dealt with here. Nodal patterns were traced out manually on the part using a crystal pickup. The nodal patterns then were transferred by scaling them on full-size drawings.

The measured frequencies are presented in Tables 6 through 11 for the ECM and conventional blades of Stages 2, 5, and 8, respectively. Frequencies up to 20,000 Hz are included.

The resulting frequencies and spread in frequencies are presented in Figures 5, 6, and 7 for Stages 2, 5, and 8, respectively.

As an example, the nodal patterns for the Stage 2 ECM blades are provided in Figures 8 through 11.



Section	Chord Overall ±0.007	Maximum +0.005 -0.002	Thickness Leading +0.005 -0.002	Trailing +0.005 -0.002
A-A	0.871	0.075	0.021	0.024
B-B	θ 0.869	θ 0.074	θ 0.023	θ 0.023
C-C	0.860	0.072	0.022	0.022
D-D	θ 0.852	θ 0.064	θ 0.021	θ 0.021
E-E	0.844	0.050	0.081	0.081
F-F	θ 0.835	θ 0.038	θ 0.016	θ 0.016
G-G	0.827	0.034	0.014	0.014
H-H	0.819	0.033	0.013	0.013

Figure 3. Stage 5 Geometry.

Table 4. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505P01.

Section	Chord		Maximum Thickness		LE Thickness		TE Thickness	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
B-B	-.0044	.0020	-.0011	.0008	-.0027	.0010	-.0022	.0012
C-C	-.0048	.0018	-.0026	.0008	-.0015	.0007	-.0012	.0011
D-D	.0037	.0017	-.0017	.0006	-.0013	.0007	.0000	.0001
E-E	.0025	.0017	.0005	.0006	-.0012	.0005	-.0005	.0009
F-F	.0024	.0017	-.0008	.0006	.0001	.0006	-.0023	.0009
G-G	.0037	.0038	-.0020	.0006	-.0006	.0007	.0005	.0009
H-H	.0051	.0067	-.0009	.0008	.0010	.0005	.0003	.0003
B-B*	-.0009	.0029	+.0023	.0008	+.0024	.0010	+.0003	.0013
D-D*	+.0007	.0035	+.0014	.0009	+.0024	.0012	+.0016	.0011
F-F*	+.0027	.0033	+.0028	.0010	+.0025	.0011	+.0017	.0011
Drawing Tolerance	+.007 -.007		+.005 -.002		+.005 -.002		+.005 -.002	

* 26 Blade Sample, PM R95

Table 5. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505P01.

SECTION	MEAS. TYPE	DRNG. TOLERANCE	SERIAL NUMBER 22	23	24	25	26	27	28	29	30	31
B-B	CHORD	+.007 -.007	-.0035	-.0010	-.0015	-.0015	+.0010	-.0030	+.0000	-.0015	+.0000	+.0000
	MAX THK	+.005 -.002	+.0010	+.0010	+.0005	+.0005	+.0010	+.0000	+.0000	+.0000	+.0000	+.0005
	LE THK	+.005 -.002	-.0010	-.0010	-.0010	-.0020	-.0010	-.0020	-.0010	-.0020	-.0015	-.0015
	TE THK	+.005 -.002	+.0005	+.0010	+.0005	+.0005	+.0015	+.0000	+.0010	+.0000	+.0005	+.0010
C-C	CHORD		+.0000	+.0015	+.0015	+.0015	+.0030	+.0005	+.0020	+.0020	+.0030	+.0040
	MAX THK		+.0000	-.0010	-.0010	-.0010	-.0005	-.0015	+.0000	+.0000	-.0010	-.0010
	LE THK		+.0000	+.0000	+.0000	-.0015	+.0000	-.0010	-.0015	-.0010	-.0015	-.0015
	TE THK		+.0015	+.0010	+.0010	+.0015	+.0020	+.0005	+.0010	+.0010	+.0010	+.0015
D-D	CHORD		+.0040	+.0040	+.0050	+.0050	+.0065	+.0040	+.0060	+.0055	+.0065	+.0075
	MAX THK		+.0000	-.0005	-.0005	-.0010	+.0000	-.0010	-.0010	-.0010	-.0010	-.0010
	LE THK		+.0000	-.0005	+.0000	-.0005	+.0000	-.0010	-.0005	-.0010	-.0005	-.0005
	TE THK		+.0020	+.0020	+.0020	+.0020	+.0030	+.0020	+.0020	+.0020	+.0025	+.0030
E-E	CHORD		+.0025	+.0025	+.0030	+.0040	+.0050	+.0020	+.0045	+.0040	+.0050	+.0055
	MAX THK		+.0020	+.0020	+.0010	+.0010	+.0025	+.0010	+.0015	+.0015	+.0010	+.0015
	LE THK		+.0000	-.0010	-.0005	-.0010	+.0000	-.0010	-.0005	-.0010	-.0010	-.0010
	TE THK		+.0020	+.0015	+.0015	+.0010	+.0020	+.0010	+.0020	+.0010	+.0015	+.0020
F-F	CHORD		+.0030	+.0025	+.0035	+.0045	+.0055	+.0030	+.0040	+.0045	+.0060	+.0060
	MAX THK		+.0000	+.0000	+.0000	+.0000	+.0005	+.0000	-.0005	+.0000	+.0000	+.0005
	LE THK		+.0010	+.0000	+.0005	+.0000	+.0010	+.0000	+.0005	+.0000	+.0005	+.0005
	TE THK		+.0000	-.0005	-.0010	-.0010	-.0005	-.0015	-.0010	-.0015	-.0005	-.0010
G-G	CHORD		+.0030	+.0020	+.0030	+.0035	+.0040	+.0020	+.0035	+.0040	+.0050	+.0060
	MAX THK		-.0010	-.0015	-.0010	-.0010	-.0005	-.0015	-.0010	-.0010	-.0010	-.0010
	LE THK		+.0000	-.0010	+.0000	-.0005	+.0000	-.0010	+.0000	-.0010	-.0010	+.0000
	TE THK		+.0020	+.0020	+.0020	+.0020	+.0030	+.0010	+.0000	+.0020	+.0020	+.0025
H-H	CHORD		+.0045	+.0020	+.0035	+.0040	+.0045	+.0030	+.0045	+.0050	+.0060	+.0075
	MAX THK		-.0010	-.0015	-.0015	-.0015	-.0020	-.0015	-.0015	-.0015	-.0015	-.0010
	LE THK		+.0015	+.0000	+.0005	+.0000	+.0000	+.0010	+.0020	+.0005	+.0000	+.0000
	TE THK		+.0020	+.0010	+.0010	+.0010	+.0015	+.0010	+.0015	+.0015	+.0015	+.0020

Table 5. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505P01 (Continued).

SECTION	MEAS. TYPE	DRNG. TOLE-RANCE	SERIAL NUMBER 32	33	34	35	36	37	38	39	40	41
B-B	CHORD	+.007 -.007	-.0025	-.0030	-.0120	-.0090	-.0020	-.0040	-.0060	-.0045	-.0040	-.0040
	MAX THK	+.005 -.002	+.0000	+.0000	-.0020	-.0020	-.0010	-.0005	-.0005	-.0005	-.0010	-.0010
	LE THK	+.005 -.002	-.0020	-.0025	-.0045	-.0040	-.0025	-.0020	-.0015	-.0020	-.0020	-.0020
	TE THK	+.005 -.002	+.0000	-.0010	-.0030	-.0030	-.0015	-.0020	-.0020	-.0030	-.0020	-.0020
C-C	CHORD		+.0010	+.0000	-.0080	-.0040	-.0010	-.0005	-.0010	+.0000	-.0010	-.0050
	MAX THK		-.0015	-.0015	-.0040	-.0035	-.0020	-.0020	-.0020	-.0020	-.0025	-.0025
	LE THK		-.0010	-.0020	-.0040	-.0030	-.0010	-.0010	-.0010	-.0010	-.0010	-.0010
	TE THK		+.0005	+.0000	-.0020	-.0020	-.0005	+.0000	+.0000	-.0005	-.0005	-.0005
D-D	CHORD		+.0050	+.0040	-.0040	-.0005	+.0030	+.0040	+.0030	+.0035	+.0030	+.0035
	MAX THK		-.0010	-.0015	-.0035	-.0035	-.0020	-.0020	-.0020	-.0020	-.0020	-.0020
	LE THK		-.0010	-.0015	-.0040	-.0030	-.0010	-.0010	-.0010	-.0010	-.0010	-.0010
	TE THK		+.0020	+.0010	-.0010	-.0010	+.0005	+.0010	+.0010	+.0000	+.0005	+.0010
E-E	CHORD		+.0035	+.0020	-.0065	-.0030	+.0015	+.0025	+.0015	+.0015	+.0015	+.0020
	MAX THK		+.0015	+.0010	-.0010	-.0015	+.0005	+.0005	+.0005	+.0005	+.0005	+.0010
	LE THK		-.0010	-.0015	-.0040	-.0030	-.0010	-.0010	-.0010	-.0010	-.0010	-.0010
	TE THK		+.0015	+.0005	-.0010	-.0020	-.0010	+.0000	-.0005	-.0010	-.0005	+.0000
F-F	CHORD		+.0040	+.0025	-.0080	-.0030	+.0010	+.0025	+.0020	+.0020	+.0020	+.0020
	MAX THK		+.0000	-.0005	-.0035	-.0030	-.0020	-.0010	-.0010	-.0010	-.0010	-.0010
	LE THK		+.0000	+.0000	-.0035	+.0000	+.0015	+.0000	+.0000	+.0000	+.0000	+.0005
	TE THK		-.0015	-.0015	-.0040	-.0040	-.0025	-.0020	-.0020	-.0025	-.0025	-.0020
G-G	CHORD		+.0035	+.0025	-.0100	-.0045	+.0010	+.0025	+.0020	+.0015	+.0025	+.0020
	MAX THK		-.0010	-.0015	-.0055	-.0040	-.0030	-.0020	-.0020	-.0020	-.0020	-.0020
	LE THK		-.0010	-.0010	-.0055	-.0030	-.0020	-.0010	-.0005	-.0010	-.0005	+.0000
	TE THK		+.0030	+.0015	-.0010	-.0010	+.0015	-.0020	+.0020	+.0015	+.0015	+.0020
H-H	CHORD		+.0050	+.0035	-.0140	+.0000	+.0020	+.0040	+.0035	+.0030	+.0040	+.0035
	MAX THK		-.0015	-.0020	-.0060	-.0045	-.0045	-.0025	-.0020	-.0020	-.0020	-.0020
	LE THK		+.0000	-.0005	+.0000	-.0010	-.0010	+.0005	+.0010	+.0005	+.0010	+.0010
	TE THK		+.0015	+.0010	-.0020	+.0000	+.0000	+.0005	+.0005	+.0000	+.0000	+.0000

Table 5. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505P01 (Continued).

SECTION	MEAS. TYPE	DRNG. TOLE-RANCE	SERIAL NUMBER 42	43	44	45	46	47	48	49	50	51
B-B	CHORD	+.007 -.007	-.0060	-.0050	-.0060	-.0050	--	-.0020	-.0020	-.0030	-.0030	-.0030
	MAX THK	+.005 -.002	-.0015	-.0010	-.0010	-.0015	--	+.0000	-.0005	-.0005	-.0010	-.0010
	LE THK	+.005 -.002	-.0030	-.0025	-.0025	-.0025	--	-.0010	-.0015	-.0015	-.0015	-.0020
	TE THK	+.005 -.002	-.0030	-.0020	-.0025	-.0020	--	-.0010	-.0010	-.0010	-.0010	-.0020
C-C	CHORD		-.0015	+.0000	-.0020	-.0010	--	+.0020	+.0015	+.0020	+.0005	+.0005
	MAX THK		-.0030	-.0015	-.0025	-.0025	--	-.0015	-.0015	-.0020	-.0030	-.0020
	LE THK		-.0005	-.0015	-.0015	-.0015	--	-.0000	-.0005	-.0005	-.0010	-.0010
	TE THK		-.0010	+.0000	-.0010	-.0010	--	-.0005	-.0005	-.0005	-.0010	-.0010
D-D	CHORD		+.0020	+.0035	+.0015	+.0025	--	+.0050	+.0050	+.0050	+.0035	+.0040
	MAX THK		-.0025	-.0020	-.0020	-.0025	--	-.0010	-.0015	-.0015	-.0020	-.0020
	LE THK		-.0015	-.0010	-.0010	-.0015	--	+.0000	-.0005	-.0005	-.0005	-.0010
	TE THK		+.0000	+.0000	+.0000	+.0005	--	+.0010	+.0010	+.0010	+.0010	+.0005
E-E	CHORD		+.0005	+.0020	+.0000	+.0010	--	+.0040	+.0035	+.0035	+.0020	+.0025
	MAX THK		-.0005	+.0005	+.0000	+.0005	--	+.0005	+.0010	+.0010	+.0005	+.0005
	LE THK		-.0015	-.0010	-.0010	-.0010	--	+.0000	-.0005	-.0010	-.0010	-.0010
	TE THK		-.0010	+.0000	-.0010	-.0005	--	+.0000	+.0000	+.0000	-.0005	-.0005
F-F	CHORD		+.0005	+.0020	+.0005	+.0015	--	+.0040	+.0040	+.0040	+.0035	+.0030
	MAX THK		-.0015	-.0010	-.0020	-.0010	--	-.0005	-.0005	-.0010	-.0015	-.0010
	LE THK		-.0005	+.0000	+.0000	+.0000	--	+.0010	+.0010	+.0005	+.0005	+.0005
	TE THK		-.0030	-.0025	-.0025	-.0020	--	-.0020	-.0010	-.0020	-.0020	-.0020
G-G	CHORD		+.0010	+.0015	+.0000	+.0020	--	+.0040	+.0040	+.0040	+.0030	+.0025
	MAX THK		-.0025	-.0020	-.0020	-.0020	--	-.0015	-.0020	-.0025	-.0025	-.0020
	LE THK		-.0010	-.0010	-.0010	-.0010	--	+.0000	-.0005	-.0010	-.0005	-.0005
	TE THK		+.0010	+.0015	+.0015	+.0015	--	+.0010	+.0020	+.0015	+.0010	+.0015
H-H	CHORD		+.0025	+.0030	+.0025	+.0040	--	+.0070	+.0060	+.0055	+.0050	+.0050
	MAX THK		-.0025	-.0020	-.0025	-.0020	--	-.0020	-.0020	-.0015	-.0015	-.0020
	LE THK		+.0000	+.0005	+.0005	+.0005	--	+.0015	+.0010	+.0010	+.0010	+.0010
	TE THK		+.0000	+.0000	+.0000	+.0000	--	+.0005	+.0005	+.0005	+.0000	+.0000

Table 5. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505P01 (Continued).

SECTION	MEAS. TYPE	DRNG. TOLE-RANCE	SERIAL NUMBER 52	53	54	55	56	57	58	59	60	61
B-B	CHORD	+.007 -.007	-.0005	-.0030	-.0015	-.0025	-.0020	-.0035	-.0010	-.0020	-.0025	-.0030
	MAX THK	+.005 -.002	-.0005	-.0005	-.0005	-.0010	+.0005	+.0000	-.0005	+.0000	-.0005	-.0010
	LE THK	+.005 -.002	-.0020	-.0020	-.0015	-.0020	-.0015	-.0010	-.0010	-.0010	-.0015	-.0015
	TE THK	+.005 -.002	-.0020	-.0020	-.0010	-.0010	-.0020	-.0010	-.0010	-.0005	-.0010	-.0010
C-C	CHORD		-.0005	+.0010	+.0015	+.0010	+.0020	-.0010	+.0020	+.0010	+.0015	+.0010
	MAX THK		-.0020	-.0020	-.0020	-.0020	-.0020	-.0015	-.0015	-.0015	-.0020	-.0020
	LE THK		-.0010	-.0010	-.0010	-.0010	-.0005	+.0000	+.0000	+.0000	-.0005	-.0005
	TE THK		+.0000	+.0000	-.0005	+.0000	+.0000	+.0000	+.0010	-.0005	+.0000	-.0010
D-D	CHORD		+.0030	+.0050	+.0050	+.0050	+.0060	+.0030	+.0060	+.0050	+.0050	+.0040
	MAX THK		-.0015	-.0020	-.0020	-.0020	-.0015	-.0010	-.0015	-.0010	-.0015	-.0020
	LE THK		-.0005	-.0005	-.0005	-.0005	-.0005	+.0000	+.0000	+.0000	-.0010	-.0010
	TE THK		+.0010	+.0010	+.0010	+.0010	+.0005	+.0010	+.0020	+.0010	+.0010	+.0005
E-E	CHORD		+.0020	+.0040	+.0040	+.0035	+.0050	+.0005	+.0050	+.0030	+.0030	+.0025
	MAX THK		+.0005	+.0005	+.0010	+.0010	+.0010	+.0010	+.0010	+.0015	+.0010	+.0005
	LE THK		-.0010	-.0010	-.0010	-.0010	-.0005	-.0005	-.0005	+.0000	-.0010	-.0010
	TE THK		-.0005	+.0000	+.0000	+.0000	+.0000	+.0000	+.0010	+.0000	+.0000	+.0000
F-F	CHORD		+.0020	+.0040	+.0040	+.0040	+.0050	+.0000	+.0050	+.0035	+.0030	+.0020
	MAX THK		-.0010	-.0005	-.0010	-.0010	-.0005	-.0010	-.0005	-.0005	-.0005	-.0010
	LE THK		+.0005	+.0005	+.0005	+.0005	+.0000	+.0000	+.0005	+.0010	+.0010	+.0005
	TE THK		-.0020	-.0020	-.0020	-.0020	-.0020	-.0015	-.0015	-.0020	-.0020	-.0020
G-G	CHORD		+.0020	+.0030	+.0040	+.0035	+.0045	+.0010	+.0050	+.0050	+.0035	+.0020
	MAX THK		-.0020	-.0020	-.0015	-.0020	-.0015	-.0020	-.0015	-.0015	-.0015	-.0020
	LE THK		-.0005	+.0000	+.0000	-.0005	+.0000	-.0010	+.0010	+.0005	+.0000	-.0005
	TE THK		+.0020	+.0015	+.0020	+.0010	+.0010	+.0010	+.0010	+.0010	+.0010	+.0005
H-H	CHORD		+.0045	+.0050	+.0055	+.0055	+.0060	+.0035	+.0060	+.0060	+.0045	+.0030
	MAX THK		-.0015	-.0020	-.0020	-.0020	-.0020	-.0015	-.0015	-.0015	-.0015	-.0020
	LE THK		+.0010	+.0010	+.0010	+.0015	+.0015	+.0015	+.0015	+.0010	+.0010	+.0005
	TE THK		+.0010	+.0005	+.0005	+.0005	+.0005	+.0005	+.0000	+.0000	+.0000	+.0000

Table 5. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505P01 (Continued).

SECTION	MEAS. TYPE	DRNG. TOLE-RANCE	SERIAL NUMBER 62	63	64	65	66	67	68	69	70	71
B-B	CHORD	+.007 -.007	-.0020	--	-.0050	-.0040	-.0050	-.0045	-.0070	-.0050	-.0035	-.0050
	MAX THK	+.005 -.002	-.0015	--	-.0015	-.0015	-.0015	-.0015	-.0015	-.0015	-.0015	-.0015
	LE THK	+.005 -.002	-.0015	--	-.0020	-.0025	-.0025	-.0025	-.0020	-.0025	-.0030	-.0030
	TE THK	+.005 -.002	-.0010	--	-.0025	-.0020	-.0020	-.0020	-.0020	-.0010	-.0020	-.0025
C-C	CHORD		+.0005	--	+.0005	+.0000	+.0005	+.0000	-.0050	+.0000	-.0005	-.0050
	MAX THK		-.0025	--	-.0025	-.0025	-.0030	-.0025	-.0025	-.0025	-.0025	-.0030
	LE THK		-.0010	--	-.0010	-.0010	-.0015	-.0010	-.0015	-.0010	-.0015	-.0020
	TE THK		-.0010	--	-.0020	-.0015	-.0015	-.0015	-.0010	-.0010	-.0015	-.0010
D-D	CHORD		+.0040	--	+.0050	+.0050	+.0045	+.0045	-.0050	+.0040	+.0035	+.0035
	MAX THK		-.0020	--	-.0015	-.0015	-.0015	-.0015	-.0015	-.0015	-.0020	-.0015
	LE THK		-.0010	--	-.0010	-.0010	-.0010	-.0010	-.0005	-.0010	-.0010	-.0005
	TE THK		+.0000	--	+.0000	+.0000	+.0000	+.0000	+.0005	+.0005	+.0000	+.0000
E-E	CHORD		+.0025	--	+.0030	+.0030	+.0030	+.0030	-.0015	+.0030	+.0025	+.0025
	MAX THK		+.0005	--	+.0005	+.0010	+.0015	+.0010	+.0005	+.0005	+.0010	+.0005
	LE THK		-.0010	--	-.0010	-.0010	-.0010	-.0010	-.0010	-.0010	-.0010	-.0010
	TE THK		-.0010	--	-.0010	+.0000	-.0010	+.0000	+.0000	+.0000	-.0010	-.0005
F-F	CHORD		+.0020	--	+.0030	+.0030	+.0025	+.0030	-.0025	+.0025	+.0020	+.0020
	MAX THK		-.0010	--	-.0010	-.0005	-.0010	-.0005	-.0010	-.0005	-.0005	-.0010
	LE THK		+.0005	--	+.0010	+.0010	+.0010	+.0010	+.0000	+.0005	+.0005	+.0005
	TE THK		-.0025	--	-.0025	-.0020	-.0025	-.0020	-.0020	-.0020	-.0025	-.0025
G-G	CHORD		+.0030	--	+.0040	+.0040	+.0030	+.0035	-.0025	+.0040	+.0030	+.0030
	MAX THK		-.0020	--	-.0020	-.0015	-.0020	-.0020	-.0020	-.0015	-.0020	-.0020
	LE THK		-.0005	--	+.0000	+.0000	+.0000	+.0000	+.0000	+.0000	+.0000	+.0000
	TE THK		+.0005	--	+.0000	+.0005	+.0000	+.0000	+.0000	+.0005	+.0000	+.0000
H-H	CHORD		+.0040	--	+.0060	+.0065	+.0065	+.0060	+.0010	+.0070	+.0060	+.0060
	MAX THK		-.0010	--	-.0020	-.0020	-.0020	-.0020	-.0020	-.0015	-.0020	-.0020
	LE THK		+.0005	--	+.0010	+.0015	+.0015	+.0010	+.0015	+.0015	+.0015	+.0015
	TE THK		+.0000	--	+.0000	+.0005	+.0000	+.0005	+.0000	+.0010	+.0000	+.0005

Table 5. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505PO1 (Continued).

SECTION	MEAS. TYPE	DRNG. TOLE-RANCE	SERIAL NUMBER 72	73	74	75	76	77	78	79	80	81
B-B	CHORD	+.007 -.007	-.0050	-.0050	-.0045	-.0030	-.0030	-.0040	-.0050	-.0040	-.0040	-.0030
	MAX THK	+.005 -.002	-.0020	-.0015	-.0010	-.0015	-.0010	-.0015	-.0015	-.0015	-.0015	-.0010
	LE THK	+.005 -.002	-.0030	-.0030	-.0025	-.0025	-.0020	-.0025	-.0030	-.0035	-.0025	-.0025
	TE THK	+.005 -.002	-.0020	-.0020	-.0020	-.0015	-.0020	-.0020	-.0030	-.0020	-.0020	-.0020
C-C	CHORD		-.0005	-.0010	+.0000	-.0015	+.0020	+.0005	-.0010	-.0005	-.0005	+.0005
	MAX THK		-.0030	-.0030	-.0025	-.0030	-.0025	-.0030	-.0030	-.0030	-.0025	-.0025
	LE THK		-.0020	-.0020	-.0010	-.0010	-.0010	-.0015	-.0015	-.0020	-.0010	-.0010
	TE THK		-.0010	-.0020	-.0010	-.0020	-.0010	-.0010	-.0020	-.0020	-.0010	-.0010
D-D	CHORD		+.0040	+.0035	+.0040	+.0030	+.0060	+.0050	+.0035	+.0035	+.0040	+.0040
	MAX THK		-.0015	-.0015	-.0015	-.0015	-.0015	-.0015	-.0020	-.0020	-.0010	-.0010
	LE THK		-.0020	-.0015	-.0010	-.0010	-.0010	-.0010	-.0015	-.0020	-.0010	-.0010
	TE THK		-.0005	-.0005	+.0005	-.0010	+.0005	+.0005	-.0005	-.0005	+.0000	+.0000
E-E	CHORD		+.0025	+.0020	+.0035	+.0015	+.0050	+.0040	+.0020	+.0020	+.0030	+.0025
	MAX THK		+.0005	+.0010	+.0005	+.0005	+.0010	+.0005	+.0000	+.0000	+.0010	+.0010
	LE THK		-.0015	-.0010	-.0010	-.0010	-.0005	-.0010	-.0010	-.0015	-.0010	-.0010
	TE THK		+.0000	-.0010	+.0000	-.0010	+.0000	+.0000	-.0010	-.0010	-.0005	+.0000
F-F	CHORD		+.0020	+.0020	+.0030	+.0010	+.0050	+.0030	+.0030	+.0020	+.0035	+.0035
	MAX THK		-.0010	-.0010	-.0010	-.0005	-.0005	-.0010	-.0010	-.0010	-.0005	-.0005
	LE THK		+.0000	+.0000	+.0005	+.0005	+.0005	+.0005	+.0000	+.0005	+.0005	+.0005
	TE THK		-.0020	-.0025	-.0020	-.0025	-.0020	-.0025	-.0025	-.0030	-.0020	-.0020
G-G	CHORD		+.0030	+.0030	+.0040	+.0035	+.0060	+.0045	+.0035	+.0035	+.0050	+.0050
	MAX THK		-.0020	-.0020	-.0015	-.0020	-.0015	-.0020	-.0020	-.0020	-.0015	-.0015
	LE THK		+.0000	+.0000	+.0000	+.0000	+.0000	+.0000	+.0000	-.0005	+.0000	+.0000
	TE THK		+.0000	+.0000	+.0005	+.0005	+.0005	+.0005	+.0000	+.0000	+.0010	+.0005
H-H	CHORD		+.0060	+.0060	+.0060	+.0065	+.0080	+.0070	+.0060	+.0055	+.0075	+.0075
	MAX THK		-.0020	-.0020	-.0020	-.0020	-.0015	-.0020	-.0020	-.0020	-.0020	-.0015
	LE THK		+.0015	+.0015	+.0015	+.0015	+.0015	+.0015	+.0010	+.0010	+.0015	+.0020
	TE THK		+.0005	+.0000	+.0005	+.0005	+.0005	+.0000	+.0000	+.0000	+.0010	+.0010

Table 5. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505P01 (Continued).

SECTION	MEAS. TYPE	DRNG. TOLE-RANCE	SERIAL NUMBER 82	83	84	85	86	87	88	89	90	91
B-B	CHORD	+.007 -.007	-.0040	-.0060	-.0060	-.0060	-.0030	-.0040	-.0035	-.0055	-.0020	-.0060
	MAX THK	+.005 -.002	-.0010	-.0020	-.0020	-.0020	-.0005	-.0005	-.0010	-.0015	-.0010	-.0015
	LE THK	+.005 -.002	-.0025	-.0030	-.0030	-.0035	-.0020	-.0020	-.0020	-.0035	-.0030	-.0035
	TE THK	+.005 -.002	-.0020	-.0020	-.0020	-.0030	-.0020	-.0015	-.0015	-.0020	-.0015	-.0030
C-C	CHORD		+.0005	-.0010	-.0010	-.0010	+.0015	-.0015	-.0010	-.0010	+.0000	-.0025
	MAX THK		-.0025	-.0030	-.0030	-.0030	-.0020	-.0020	-.0030	-.0025	-.0020	-.0030
	LE THK		-.0010	-.0020	-.0015	-.0020	-.0010	-.0010	-.0010	-.0020	-.0010	-.0020
	TE THK		-.0010	-.0020	-.0015	-.0020	-.0010	-.0010	-.0015	-.0015	-.0015	-.0015
D-D	CHORD		+.0050	+.0030	+.0035	+.0030	+.0050	+.0050	+.0045	+.0030	+.0040	+.0015
	MAX THK		-.0010	-.0020	-.0020	-.0020	-.0005	-.0005	-.0010	-.0015	-.0010	-.0015
	LE THK		-.0010	-.0020	-.0020	-.0020	-.0010	-.0010	-.0010	-.0020	-.0015	-.0020
	TE THK		-.0000	+.0000	+.0000	+.0000	+.0005	+.0010	+.0000	-.0005	+.0000	-.0005
E-E	CHORD		+.0040	+.0010	+.0020	+.0020	+.0045	+.0040	+.0035	+.0015	+.0035	+.0010
	MAX THK		+.0010	+.0005	+.0005	+.0000	+.0000	+.0015	+.0005	+.0000	+.0015	+.0005
	LE THK		-.0010	-.0015	-.0010	-.0020	-.0010	-.0010	-.0010	-.0015	-.0010	-.0010
	TE THK		+.0000	-.0010	-.0010	-.0010	+.0000	+.0000	-.0005	-.0010	-.0005	-.0010
F-F	CHORD		+.0035	+.0010	+.0025	+.0020	+.0045	+.0040	+.0040	+.0020	+.0035	+.0015
	MAX THK		-.0005	-.0010	-.0010	-.0010	+.0000	+.0000	-.0005	-.0010	+.0000	-.0010
	LE THK		+.0005	+.0000	+.0000	+.0000	+.0010	+.0010	+.0005	-.0005	-.0010	+.0000
	TE THK		-.0020	-.0020	-.0025	-.0030	-.0020	-.0010	-.0020	-.0025	-.0020	-.0025
G-G	CHORD		+.0055	+.0025	+.0040	+.0030	+.0060	+.0060	+.0055	+.0035	+.0045	+.0030
	MAX THK		-.0015	-.0020	-.0020	-.0025	-.0010	-.0015	-.0015	-.0020	-.0015	-.0020
	LE THK		+.0000	-.0005	+.0000	-.0010	+.0000	+.0005	-.0000	-.0005	-.0005	-.0010
	TE THK		+.0005	+.0000	+.0000	+.0000	+.0010	+.0010	+.0000	+.0000	+.0005	+.0000
H-H	CHORD		+.0080	+.0050	+.0070	+.0050	+.0010	+.0090	+.0090	+.0060	+.0070	+.0050
	MAX THK		-.0015	-.0020	-.0020	-.0010	-.0015	-.0015	-.0015	-.0020	-.0015	-.0020
	LE THK		+.0015	+.0010	+.0015	+.0010	+.0020	+.0020	+.0020	+.0010	+.0015	+.0010
	TE THK		+.0010	+.0025	+.0025	+.0000	+.0010	+.0015	+.0010	+.0005	+.0005	+.0005

Table 5. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505P01 (Continued).

SECTION	MEAS. TYPE	DRNG. TOLE-RANCE	SERIAL NUMBER 92	93	94	95	96	97	98	99	100	101
B-B	CHORD	+.007 -.007	-.0055	-.0060	-.0040	-.0060	-.0040	-.0070	-.0045	-.0060	-.0055	-.0050
	MAX THK	+.005 -.002	-.0015	-.0010	-.0010	-.0015	-.0020	-.0020	-.0015	-.0020	-.0020	-.0020
	LE THK	+.005 -.002	-.0030	-.0030	-.0030	-.0045	-.0035	-.0035	-.0030	-.0040	-.0035	-.0030
	TE THK	+.005 -.002	-.0030	-.0030	-.0025	-.0030	-.0030	-.0030	-.0030	-.0030	-.0030	-.0030
C-C	CHORD		-.0010	-.0010	-.0010	-.0020	-.0020	-.0020	-.0010	-.0015	-.0010	-.0005
	MAX THK		-.0030	-.0025	-.0025	-.0025	-.0030	-.0030	-.0030	-.0030	-.0030	-.0030
	LE THK		-.0020	-.0015	-.0010	-.0030	-.0020	-.0020	-.0015	-.0025	-.0025	-.0015
	TE THK		-.0020	-.0015	-.0015	-.0015	-.0030	-.0020	-.0020	-.0020	-.0025	-.0020
D-D	CHORD		+.0030	+.0025	+.0045	+.0025	+.0020	+.0020	+.0035	+.0035	+.0035	+.0045
	MAX THK		-.0020	-.0015	-.0010	-.0015	-.0020	-.0020	-.0015	-.0020	-.0020	-.0020
	LE THK		-.0015	-.0015	-.0015	-.0025	-.0020	-.0020	-.0010	-.0020	-.0020	-.0015
	TE THK		-.0005	-.0005	+.0000	-.0005	-.0005	-.0010	+.0000	+.0000	-.0010	+.0000
E-E	CHORD		+.0020	+.0010	+.0030	+.0020	+.0010	+.0050	+.0030	+.0020	+.0020	+.0030
	MAX THK		+.0005	+.0005	+.0005	+.0010	+.0010	+.0000	+.0005	-.0005	+.0000	+.0000
	LE THK		-.0010	-.0010	-.0010	-.0020	-.0015	-.0020	-.0010	-.0020	-.0015	-.0015
	TE THK		-.0010	-.0010	-.0005	-.0010	-.0010	-.0015	-.0010	-.0010	-.0015	-.0010
F-F	CHORD		+.0020	+.0010	+.0035	+.0015	+.0010	+.0005	+.0030	+.0020	+.0020	+.0030
	MAX THK		-.0015	-.0010	-.0005	-.0005	-.0015	-.0015	-.0010	-.0015	-.0015	-.0015
	LE THK		-.0005	+.0000	+.0005	-.0005	-.0005	+.0005	+.0000	-.0010	-.0005	+.0000
	TE THK		-.0030	-.0030	-.0020	-.0025	-.0030	-.0030	-.0025	-.0030	-.0030	-.0025
G-G	CHORD		+.0040	+.0020	+.0045	+.0030	+.0025	+.0020	+.0050	+.0040	+.0045	+.0040
	MAX THK		-.0025	-.0020	-.0015	-.0015	-.0020	-.0025	-.0015	-.0025	-.0025	-.0020
	LE THK		-.0010	-.0005	+.0000	-.0010	-.0010	-.0010	-.0005	-.0010	-.0010	-.0010
	TE THK		+.0000	+.0000	+.0005	+.0000	+.0000	+.0000	+.0000	+.0000	+.0000	+.0000
H-H	CHORD		-.0065	+.0060	+.0070	-.0050	+.0050	-.0055	+.0080	+.0055	+.0070	+.0060
	MAX THK		-.0020	-.0020	-.0015	-.0020	-.0020	-.0020	-.0020	-.0020	-.0020	-.0020
	LE THK		+.0010	+.0010	+.0015	+.0010	+.0010	+.0005	+.0015	+.0005	+.0010	+.0010
	TE THK		+.0000	+.0005	+.0005	+.0000	+.0000	+.0000	+.0005	+.0000	+.0000	+.0000

Table 5. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505P01 (Continued).

SECTION	MEAS. TYPE	DRNG. TOLE-RANCE	SERIAL NUMBER 102	103	104	105	106	107	108	110	111	112
B-B	CHORD	+.007 -.007	-.0050	-.0070	-.0070	-.0050	-.0070	-.0060	-.0040	-.0055	-.0050	-.0055
	MAX THK	+.005 -.002	-.0020	-.0020	-.0020	-.0020	-.0020	-.0020	-.0020	-.0020	-.0020	-.0020
	LE THK	+.005 -.002	-.0030	-.0035	-.0035	-.0030	-.0040	-.0030	-.0030	-.0035	-.0030	-.0035
	TE THK	+.005 -.002	-.0030	-.0040	-.0030	-.0030	-.0040	-.0030	-.0020	-.0030	-.0030	-.0030
C-C	CHORD		+.0000	-.0030	-.0025	-.0010	-.0015	-.0010	+.0000	+.0000	+.0000	-.0005
	MAX THK		-.0030	-.0035	-.0035	-.0035	-.0035	-.0030	-.0030	-.0035	-.0030	-.0030
	LE THK		-.0020	-.0020	-.0020	-.0020	-.0020	-.0020	-.0015	-.0020	-.0020	-.0025
	TE THK		-.0020	-.0025	-.0025	-.0025	-.0025	-.0020	-.0015	-.0020	-.0015	-.0015
D-D	CHORD		+.0060	+.0020	+.0020	+.0040	+.0025	+.0040	+.0050	+.0040	+.0045	+.0045
	MAX THK		-.0020	-.0020	-.0020	-.0020	-.0025	-.0020	-.0020	-.0020	-.0020	-.0020
	LE THK		-.0015	-.0020	-.0020	-.0020	-.0020	-.0020	-.0015	-.0020	-.0020	-.0020
	TE THK		+.0000	-.0010	-.0010	-.0010	-.0010	-.0005	-.0000	-.0010	+.0000	-.0005
E-E	CHORD		+.0030	+.0005	+.0005	+.0020	+.0010	+.0020	+.0035	+.0020	+.0030	+.0030
	MAX THK		+.0000	+.0000	+.0000	+.0000	+.0000	-.0005	+.0000	+.0000	+.0005	+.0005
	LE THK		-.0015	-.0020	-.0015	-.0015	-.0020	-.0015	-.0010	-.0015	-.0015	-.0015
	TE THK		-.0010	-.0020	-.0015	-.0015	-.0020	-.0015	-.0005	-.0015	-.0005	-.0010
F-F	CHORD		+.0030	+.0010	+.0010	+.0020	+.0010	+.0015	+.0030	+.0020	+.0030	+.0035
	MAX THK		-.0010	-.0015	-.0010	-.0010	-.0010	-.0005	-.0005	-.0005	-.0005	-.0005
	LE THK		+.0000	-.0010	+.0000	+.0000	+.0000	-.0005	+.0000	+.0000	-.0005	+.0000
	TE THK		-.0030	-.0030	-.0025	-.0030	-.0035	-.0030	-.0025	-.0030	-.0025	-.0030
G-G	CHORD		+.0050	+.0020	+.0025	+.0035	+.0020	+.0030	+.0045	+.0040	+.0050	+.0045
	MAX THK		-.0020	-.0035	-.0025	-.0025	-.0030	-.0025	-.0020	-.0025	-.0020	-.0020
	LE THK		-.0010	-.0015	-.0010	-.0010	-.0010	-.0010	-.0005	-.0010	-.0005	-.0005
	TE THK		+.0000	+.0005	+.0000	-.0005	-.0010	-.0005	+.0000	-.0005	+.0000	+.0000
H-H	CHORD		+.0065	+.0040	+.0050	+.0050	+.0045	+.0055	+.0070	+.0060	+.0070	+.0065
	MAX THK		-.0020	-.0025	-.0020	-.0020	-.0025	-.0025	-.0020	-.0025	-.0020	-.0020
	LE THK		+.0010	+.0005	+.0010	+.0010	+.0005	+.0010	+.0010	+.0005	+.0010	+.0010
	TE THK		+.0000	+.0000	+.0000	-.0005	+.0000	+.0000	+.0000	+.0000	+.0000	+.0000

Table 5. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505P01 (Continued).

SECTION	MEAS. TYPE	DRNG. TOLE- RANCE	SERIAL NUMBER 113	114	115	116	117	118	119	120	121	122
B-B	CHORD	+.007 -.007	-0070	-.0050	-.0040	-.0060	-.0050	-.0050	-.0070	-.0055	-.0070	-.0085
	MAX THK	+.005 -.002	-.0015	-.0010	-.0015	-.0010	-.0020	-.0015	-.0020	-.0020	-.0020	-.0020
	LE THK	+.005 -.002	-.0040	-.0040	-.0035	-.0035	-.0035	-.0035	-.0040	-.0035	-.0040	-.0035
	TE THK	+.005 -.002	-.0040	-.0030	-.0035	-.0030	-.0040	-.0030	-.0040	-.0030	-.0040	-.0040
C-C	CHORD		-.0020	-.0005	+.0000	-.0060	-.0020	-.0010	-.0015	-.0010	-.0040	-.0030
	MAX THK		-.0030	-.0030	-.0030	-.0035	-.0035	-.0035	-.0040	-.0035	-.0035	-.0040
	LE THK		-.0020	-.0020	-.0020	-.0030	-.0020	-.0020	-.0025	-.0020	-.0025	-.0030
	TE THK		-.0020	-.0020	-.0020	-.0025	-.0025	-.0025	-.0020	-.0020	-.0030	-.0025
D-D	CHORD		+.0030	+.0040	+.0045	+.0000	+.0025	+.0040	+.0035	+.0035	+.0025	+.0015
	MAX THK		-.0020	-.0020	-.0020	-.0020	-.0020	-.0020	-.0025	-.0020	-.0020	-.0030
	LE THK		-.0015	-.0020	-.0020	-.0020	-.0020	-.0020	-.0025	-.0020	-.0020	-.0030
	TE THK		-.0005	-.0005	-.0010	-.0010	-.0010	-.0010	-.0005	-.0010	-.0010	-.0010
E-E	CHORD		+.0015	+.0025	+.0025	-.0010	+.0015	+.0025	+.0025	+.0015	+.0005	-.0005
	MAX THK		+.0000	+.0005	+.0000	+.0000	-.0005	+.0000	-.0005	+.0000	+.0000	-.0005
	LE THK		-.0015	-.0015	-.0015	-.0020	-.0020	-.0015	-.0020	-.0015	-.0020	-.0025
	TE THK		-.0010	-.0010	-.0015	-.0010	-.0015	-.0010	-.0010	-.0010	-.0015	-.0020
F-F	CHORD		+.0020	+.0025	+.0025	-.0015	+.0020	+.0025	+.0020	+.0020	+.0010	+.0000
	MAX THK		-.0010	-.0005	-.0010	-.0005	-.0010	-.0005	-.0005	-.0010	-.0010	-.0015
	LE THK		+.0000	-.0005	+.0000	-.0010	-.0005	+.0000	-.0005	-.0010	-.0010	+.0000
	TE THK		-.0030	-.0030	-.0030	-.0030	-.0030	-.0030	-.0030	-.0030	-.0030	-.0035
G-G	CHORD		+.0040	+.0045	+.0040	-.0010	+.0040	+.0050	+.0035	+.0040	+.0030	+.0015
	MAX THK		-.0025	-.0020	-.0025	-.0025	-.0025	-.0025	-.0025	-.0025	-.0025	-.0035
	LE THK		-.0005	-.0010	-.0010	-.0010	-.0010	-.0010	-.0010	-.0005	-.0010	-.0015
	TE THK		+.0000	+.0000	+.0000	+.0015	+.0000	+.0000	-.0005	+.0000	-.0005	-.0010
H-H	CHORD		+.0065	+.0070	+.0060	+.0000	+.0060	+.0070	+.0055	+.0065	+.0050	+.0040
	MAX THK		-.0020	-.0020	-.0020	-.0020	-.0025	-.0020	-.0020	-.0020	-.0020	-.0030
	LE THK		+.0010	+.0010	+.0005	+.0005	+.0010	+.0010	+.0010	+.0010	+.0010	+.0010
	TE THK		-.0005	+.0000	+.0000	-.0000	+.0000	+.0000	+.0000	+.0000	+.0000	-.0005

Table 5. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505P01 (Continued).

SECTION	MEAS. TYPE	DRNG. TOLE-RANCE	SERIAL NUMBER 123	124	125	126	127	128	129	130	109	131
B-B	CHORD	+.007 -.007	-.0060	-.0060	-.0070	-.0040	-.0060	-.0065	-.0065	-.0055	-.0035	-.0045
	MAX THK	+.005 -.002	-.0010	-.0010	-.0015	-.0010	-.0010	-.0015	-.0015	-.0010	-.0010	-.0015
	LE THK	+.005 -.002	-.0030	-.0030	-.0035	-.0025	-.0030	-.0035	-.0035	-.0035	-.0030	-.0035
	TE THK	+.005 -.002	-.0040	-.0040	-.0030	-.0030	-.0030	-.0040	-.0030	-.0030	-.0030	-.0030
C-C	CHORD		-.0020	-.0005	-.0010	+.0005	-.0005	-.0010	-.0020	+.0000	+.0010	-.0015
	MAX THK		-.0030	-.0030	-.0030	-.0030	-.0025	-.0025	-.0035	-.0030	-.0030	-.0035
	LE THK		-.0015	-.0020	-.0025	-.0010	-.0020	-.0020	-.0020	-.0020	-.0015	-.0020
	TE THK		-.0025	-.0020	-.0020	-.0020	-.0020	-.0020	-.0025	-.0015	-.0010	-.0020
D-D	CHORD		+.0030	+.0045	+.0030	+.0050	+.0040	+.0035	+.0040	+.0045	+.0055	+.0040
	MAX THK		-.0020	-.0020	-.0020	-.0015	-.0020	-.0020	-.0020	-.0015	-.0015	-.0020
	LE THK		-.0015	-.0020	-.0020	+.0000	-.0020	-.0020	-.0020	-.0020	-.0015	-.0020
	TE THK		-.0010	-.0010	-.0010	-.0010	-.0010	-.0010	-.0010	+.0000	+.0000	-.0005
E-E	CHORD		+.0015	+.0020	+.0020	+.0040	+.0025	+.0020	+.0020	+.0030	+.0040	+.0020
	MAX THK		+.0005	+.0000	+.0000	+.0010	+.0005	+.0000	+.0000	+.0005	+.0005	+.0000
	LE THK		-.0010	-.0010	-.0020	-.0010	-.0005	-.0015	-.0020	-.0005	-.0010	-.0015
	TE THK		-.0010	-.0010	-.0020	-.0010	-.0010	-.0010	-.0015	-.0010	-.0010	-.0010
F-F	CHORD		+.0020	+.0030	+.0020	+.0040	+.0020	+.0020	+.0020	+.0020	+.0045	+.0025
	MAX THK		+.0000	+.0000	-.0005	+.0000	-.0005	-.0015	-.0010	+.0000	+.0000	+.0000
	LE THK		+.0000	+.0000	-.0005	-.0005	+.0000	+.0000	-.0010	+.0000	+.0000	+.0000
	TE THK		-.0030	-.0030	-.0030	-.0025	-.0030	-.0030	-.0030	-.0025	-.0025	-.0030
G-G	CHORD		+.0007	+.0055	+.0040	+.0050	+.0035	+.0035	+.0050	+.0050	+.0000	+.0050
	MAX THK		-.0025	-.0025	-.0025	-.0020	-.0025	-.0025	-.0025	-.0020	-.0020	-.0025
	LE THK		-.0005	-.0005	-.0010	+.0000	-.0010	-.0010	-.0010	-.0005	+.0000	-.0005
	TE THK		+.0000	+.0000	+.0000	+.0000	-.0005	+.0000	+.0000	+.0000	+.0005	+.0000
H-H	CHORD		+.0060	+.0080	+.0060	+.0080	+.0060	+.0060	+.0070	+.0070	+.0090	+.0080
	MAX THK		-.0020	-.0025	-.0015	-.0015	-.0020	-.0020	-.0020	-.0020	-.0015	-.0020
	LE THK		+.0010	+.0010	+.0005	+.0015	+.0010	+.0010	+.0010	+.0010	+.0010	+.0010
	TE THK		+.0000	+.0005	+.0000	+.0010	+.0000	+.0000	+.0000	+.0005	+.0000	+.0000

Table 5. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505P01 (Continued).

SECTION	MEAS. TYPE	DRNG. TOLE-RANCE	SERIAL NUMBER 132	133	134	135	136	137	138	139	140	141
B-B	CHORD	+.007 -.007	-.0040	-.0025	-.0035	-.0050	-.0045	-.0050	-.0060	-.0055	-.0040	-.0020
	MAX THK	+.005 -.002	-.0010	-.0010	-.0015	-.0020	-.0015	-.0015	-.0020	-.0010	-.0015	+.0000
	LE THK	+.005 -.002	-.0080	-.0030	-.0030	-.0030	-.0030	-.0035	-.0040	-.0035	-.0030	-.0020
	TE THK	+.005 -.002	-.0035	-.0025	-.0030	-.0030	-.0040	-.0030	-.0030	-.0030	-.0020	-.0020
C-C	CHORD		+.0000	+.0015	+.0015	+.0000	+.0000	+.0000	-.0010	+.0000	+.0000	+.0005
	MAX THK		-.0040	-.0030	-.0035	-.0035	-.0035	-.0035	-.0040	-.0030	-.0030	-.0025
	LE THK		-.0015	-.0015	-.0015	-.0020	-.0020	-.0025	-.0025	-.0020	-.0020	-.0015
	TE THK		-.0010	-.0015	-.0020	-.0025	-.0020	-.0020	-.0020	-.0020	-.0010	-.0020
D-D	CHORD		+.0050	+.0070	+.0060	+.0040	+.0050	+.0050	+.0035	+.0040	+.0045	+.0050
	MAX THK		-.0015	-.0015	-.0020	-.0020	-.0020	-.0020	-.0025	-.0020	-.0020	-.0010
	LE THK		-.0010	-.0015	-.0015	-.0015	-.0015	-.0020	-.0020	-.0010	-.0010	-.0010
	TE THK		+.0010	+.0000	-.0010	-.0010	-.0010	-.0005	-.0010	-.0010	+.0000	+.0000
E-E	CHORD		+.0050	+.0050	+.0045	+.0030	+.0040	+.0035	+.0020	+.0025	+.0040	+.0040
	MAX THK		+.0010	+.0005	+.0000	+.0000	+.0005	+.0000	-.0005	+.0000	+.0000	+.0015
	LE THK		-.0010	-.0010	-.0015	-.0015	-.0010	-.0015	-.0015	-.0010	-.0010	-.0010
	TE THK		+.0000	-.0005	-.0010	-.0015	-.0010	-.0010	-.0020	-.0010	+.0000	+.0000
F-F	CHORD		+.0045	+.0050	+.0040	+.0030	+.0035	+.0030	+.0020	+.0020	+.0035	+.0030
	MAX THK		+.0000	+.0000	-.0005	-.0005	+.0000	-.0005	-.0010	-.0005	+.0000	+.0005
	LE THK		+.0005	+.0000	+.0000	+.0000	-.0005	+.0000	-.0010	-.0005	+.0000	+.0000
	TE THK		-.0020	-.0025	-.0030	-.0030	-.0030	-.0030	-.0030	-.0030	-.0025	-.0030
G-G	CHORD		+.0060	+.0070	+.0060	+.0045	+.0050	+.0050	+.0040	+.0040	+.0045	+.0040
	MAX THK		-.0015	-.0020	-.0020	-.0025	-.0025	-.0025	-.0025	-.0020	-.0020	-.0020
	LE THK		+.0000	+.0000	-.0010	-.0010	-.0005	-.0010	-.0010	-.0005	-.0005	+.0000
	TE THK		+.0005	+.0000	-.0005	-.0005	+.0000	+.0000	-.0005	+.0000	+.0000	-.0010
H-H	CHORD		+.0080	+.0090	+.0005	+.0070	+.0080	+.0070	+.0065	+.0065	+.0070	+.0060
	MAX THK		-.0015	-.0015	-.0020	-.0020	-.0020	-.0020	-.0025	-.0020	-.0020	-.0025
	LE THK		+.0015	+.0015	+.0010	+.0010	+.0010	+.0010	+.0010	+.0010	+.0015	+.0010
	TE THK		+.0005	+.0000	+.0000	-.0005	+.0000	+.0000	-.0005	+.0000	+.0000	+.0000

Table 5. Geometry Summary, Stage 5 ECM'd Airfoil, Part No. 4013148-505P01 (Concluded).

SECTION	MEAS. TYPE	DRNG. TOLE-RANCE	SERIAL NUMBER 142								
B-B	CHORD	+.007 -.007	-.0035								
	MAX THK	+.005 -.002	+.0000								
	LE THK	+.005 -.002	-.0020								
	TE THK	+.005 -.002	-.0020								
C-C	CHORD		+.0000								
	MAX THK		-.0025								
	LE THK		-.0015								
	TE THK		-.0020								
D-D	CHORD		+.0045								
	MAX THK		-.0010								
	LE THK		-.0010								
	TE THK		-.0005								
E-E	CHORD		+.0030								
	MAX THK		+.0010								
	LE THK		-.0010								
	TE THK		-.0010								
F-F	CHORD		+.0025								
	MAX THK		+.0005								
	LE THK		+.0000								
	TE THK		-.0025								
G-G	CHORD		+.0035								
	MAX THK		-.0020								
	LE THK		+.0000								
	TE THK		+.0000								
H-H	CHORD		+.0070								
	MAX THK		-.0025								
	LE THK		+.0010								
	TE THK		+.0000								

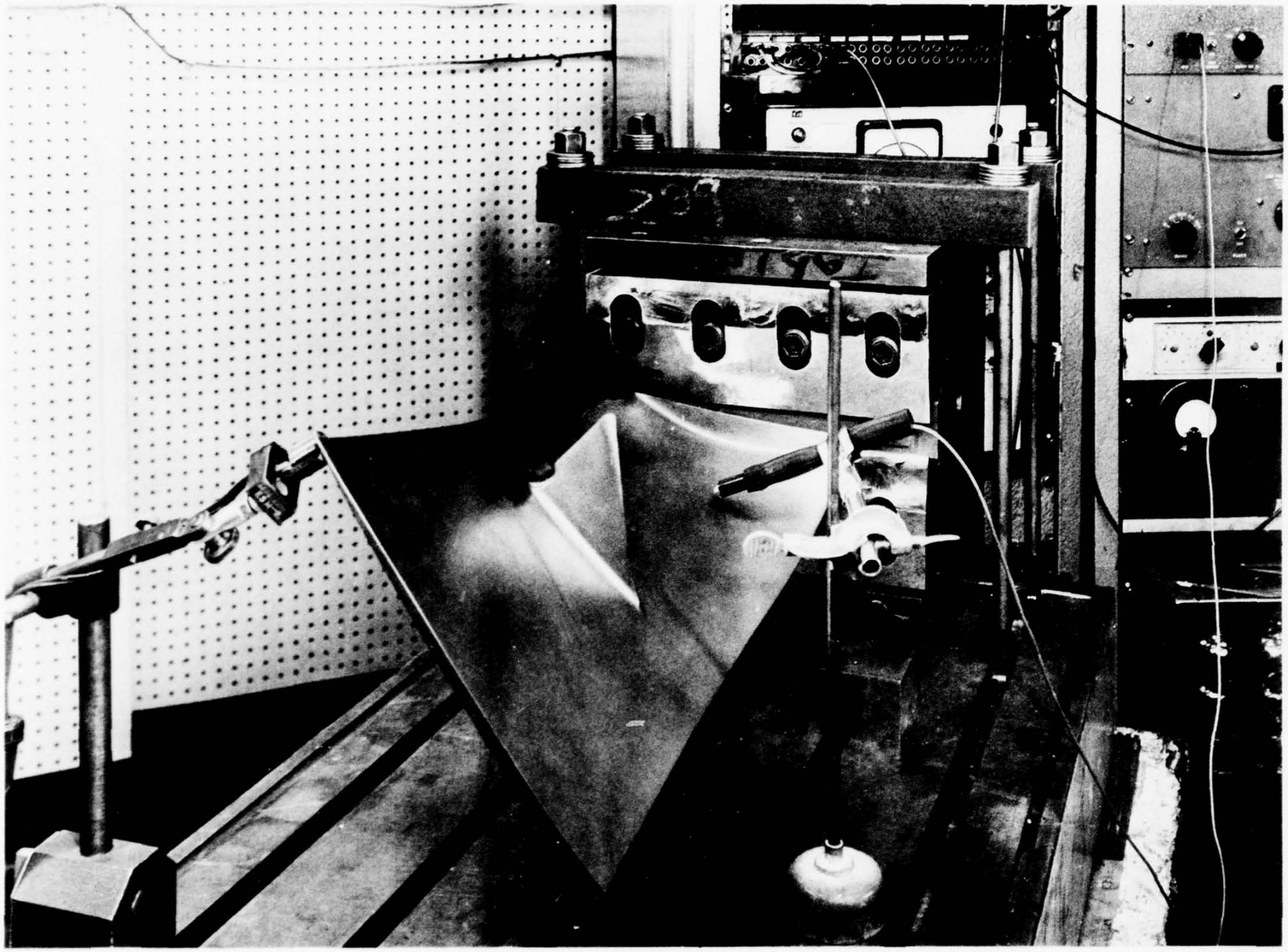


Figure 4. Typical Test Setup for Natural Frequencies and Nodal Patterns.

Table 6. ECM'd Stage 2 Blades, Part No. 4013148-502.

Item	Mode Number										
	1	2	3	4	5	6	7	8	9	10	11
S/N 367	794	2534	3370	5554	6320	7480	7916	9848	12034	12714	14356
131	806	2558	3330	5504	6332	7480	7784	9540	11640	12286	13834
168	792	2502	3330	5492	6128	7496	7938	9806	12302	12726	14556
115	804	2552	3388	5554	6160	7622	8002	9888	12374	12780	14662
354	786	2506	3388	5646	6242	7664	8056	10024	12392	13028	14958
187	788	2476	3304	5432	6090	7406	7770	9576	12370	---	14262
139	790	2522	3380	5576	6162	7668	8090	10014	12626	12978	15048
121	792	2536	3396	5570	---	7648	8096	9936	12480	12822	14914
357	766	2470	3298	5410	6202	7410	7700	9508	12212	12376	14312
356	820	2594	3504	5760	6326	7840	8280	10286	12684	13484	15420
155	796	2518	3386	5580	6120	7630	8044	9986	12594	12950	---
149	798	2522	3376	5520	---	7494	7950	9790	12224	12754	14368
107	784	2496	3332	5496	6076	7544	7988	9832	12368	12696	14662
358	804	2572	3414	5638	6120	7760	8232	10108	12804	13210	15334
159	796	2538	3348	5512	---	7582	7984	9848	12376	12754	14696
No. of Samples	15	15	15	15	12	15	15	15	15	14	14
Unbiased: Mean	794.4	2526.4	3369.6	5549.6	6189.8	7581.6	7988.7	9866	12365.3	12825.6	14670.1
Std Dev	12.10	34.18	50.90	87.56	93.78	124.95	159.47	212.36	281.79	304.55	437.29

NOTE: All frequencies in Hertz.

Table 7. Conventional Stage 2 Blades, Part No. 4013148-502.

Item	Mode Number										
	1	2	3	4	5	6	7	8	9	10	11
S/N 107	812	2596	3566	5694	6130	7726	8236	10216	12276	13322	14754
103	802	2562	3550	5528	6138	7680	8124	10176	12250	13216	14800
105	802	2546	3524	5678	6102	7802	8214	10484	12332	13410	15218
114	818	2582	3530	5680	6154	7762	8262	10546	12476	13500	14972
109	806	2562	3504	5630	6168	7822	8168	10144	12308	13092	15096
101	822	2594	3548	5686	6208	7816	8190	10526	12486	13492	15238
110	806	2570	3458	5618	6156	7742	8182	10230	---	13160	15050
113	794	2546	3446	5636	6228	7802	8206	10272	12448	13400	15216
108	790	2522	3420	5550	6100	7656	8036	10096	12248	12866	14836
104	804	2578	3202	5724	6292	7680	8128	10228	12296	13214	14848
106	776	2504	3382	5524	6028	7584	7972	9962	12250	12714	14716
115	826	2586	3552	5688	6238	7722	8240	10420	12292	13386	14850
102	800	2574	3486	5744	6200	7852	8406	10434	12438	13722	15186
111	810	2588	3506	5672	6158	7724	8224	10458	12408	13416	14828
112	828	2602	3516	5720	6168	7852	8268	10450	12424	13482	15158
No. of Samples	15	15	15	15	15	15	15	15	14	15	15
Unbiased:											
Mean	806	2568	3481	5652	6165	7748	8190	10310	12352	13293	14984
Std Dev	14	28	93	70	64	78	102	177	90	259	189

NOTE: All frequencies in Hertz.

Table 8. ECM'd Stage 5 Blades, Part No. 4013148-505.

Item	Mode Number							
	1	2	3	4	5	6	7	8
S/N 71	1678	4226	5578	6700	9360	12536	13550	16976
127	1664	4204	5108	6450	9324	12442	13172	16802
33	1684	4224	5172	6502	9388	12600	13306	17060
123	1676	4218	5610	6790	9340	12354	13632	17052
77	1666	4212	5514	6608	9346	12604	13630	17108
139	1680	4238	5466	6620	9320	12566	13466	16938
58	1678	4226	5192	6488	9408	12606	13428	17166
41	1680	4232	5460	6668	9348	12602	13542	18064
30	1702	4290	5556	6722	9478	12776	13598	17284
48	1684	4242	5478	6618	9424	12674	13556	17238
66	1664	4198	5270	6512	9318	12496	13344	17056
112	1662	4182	5038	6448	9216	12906	13204	16858
132	1664	4206	5362	6524	9362	12568	13430	17024
61	1686	4240	5462	6662	9376	12566	13536	17032
39	1690	4244	5476	6654	9368	12632	13470	17006
137	1658	4168	5272	6518	9372	12446	13396	16912
53	1674	4222	5168	6454	9364	12608	13350	17008
94	1666	4200	5278	6538	9358	12562	13412	17040
28	1680	4244	5388	6558	9444	12694	13508	17212
37	1670	4144	4698	6356	9294	12394	13434	16978
No. of Samples	20	20	20	20	20	20	20	20
Unbiased:								
Mean	1675	4218	5327	6570	9360	1258	13448	17041
Std Dev	11	31	222	110	56	127	129	121
Mean*	1731	4470	5722	6917	10024	12668	13937	---
Std Dev*	10	48	49	45	255	368	286	---

* 26 Blade Sampl, PM R95
Note: All Frequences in Hz

Table 9. Conventional Stage 5 Blades, Part No. 4013148-505.

Item	Mode Number										
	1	2	3	4	5	6	7	8	9	10	11
S/N 151	1572	4213	5173	6437	9810	12956	14348	15564	17441	18216	19470
143	1675	4390	5309	6510	9939	13114	14763	16056	17882	18485	19770
152	1618	4268	5076	6432	9959	13020	14592	16159	17253	18305	19251
153	1624	4295	5124	6438	10027	13015	14656	16035	17517	18398	19286
144	1582	4214	5057	---	9932	13211	14699	16180	17432	18393	19418
148	1612	4290	5154	---	9830	13306	14612	15883	16717	18238	19403
156	1553	4222	5048	6513	9884	13108	14631	15823	17735	18418	19585
157	1646	4252	5248	6362	9402	12722	13873	15684	17020	17739	19526
154	1707	4378	5380	---	9476	12785	14043	15827	17419	17973	20022
150	1613	4281	5208	6519	9932	13231	14833	16318	17562	18485	19572
149	1581	4308	5179	---	9864	13186	14845	16106	17763	18479	19683
147	1643	4336	5308	6501	9727	13135	14397	15780	17024	18159	19691
158	1615	4312	5154	6642	10215	13465	14812	16457	17783	18530	19892
155	1608	4294	5217	6648	10242	13387	14911	16246	17639	18589	19675
145	1627	4264	5162	6536	9952	13158	14519	16317	17867	18496	20043
159	1618	4299	5088	6543	9980	13167	14791	16529	17781	18440	19871
161	1612	4297	5163	6451	9795	13192	14729	15963	17692	18414	19683
141	1592	4255	5155	6432	9987	13398	15158	16215	17834	18591	19717
146	1590	4279	5032	6371	9633	13356	14513	15868	17970	19429	21046
140	1583	4265	5199	6580	10269	13401	14992	16288	17661	18654	19767
No. of Samples	20	20	20	17	20	20	20	20	20	20	20
Unbiased: Mean	1614	4286	5177	6495	9293	13166	14636	16065	17550	18421	19718
Std Dev	34.8	46.7	93.4	84.4	223.1	198.4	303.1	261.7	330.8	322.9	380.9

NOTE: All frequencies in Hertz.

Table 10. ECM'd Stage 8 Blades, Part No. 4013148-508.

Item	Mode Number						
	1	2	3	4	5	6	7
S/N 119	2558	5512	10850	13790	15268	---	---
141	2590	5610	10092	14130	15414	---	---
58	2556	5528	10212	13626	---	---	---
29	2632	5646	10340	13866	15924	---	---
112	2550	5580	9958	13524	---	---	---
33	2564	5490	9966	13544	15074	16224	---
93	2638	5662	10346	14018	15766	---	---
123	2618	5636	10230	13902	15432	16592	---
153	2654	5664	10368	14174	15550	16174	---
147	2702	5752	10254	14084	---	16796	17256
63	2552	5516	9942	13502	15690	---	---
138	2626	5442	10354	14116	---	16500	---
133	2608	5544	10250	13940	15756	---	---
111	2636	5620	10190	13738	---	16270	16868
115	2628	5616	10274	13612	15612	16480	19114
150	2692	5726	10410	14288	---	16884	---
90	2673	5682	10520	13914	15780	---	---
96	2642	5646	10400	14064	15792	---	---
131	2614	5612	10034	13498	15562	---	---
113	2646	5722	10144	13986	---	16468	---
No. of Samples	20	20	20	20	13	6	1
Unbiased: Mean	2619	5610	10257	13841	15586	Insufficient Data	
Std Dev	84	84	214	272	239		
NOTE: All frequencies in Hertz.							

Table 11. Conventional Stage 8 Blades, Part No. 4013148-508.

Item	Mode Number						
	1	2	3	4	5	6	7
S/N 114	2684	5645	10950	14596	16038	17064	19820
136	2695	5705	11012	14752	16578	17435	20479
5	2710	5691	10904	14584	15947	17258	19815
116	2648	5669	10926	14738	16303	17877	20413
140	2800	5859	11163	14853	16352	17858	20328
137	2639	5583	10870	14728	15979	17559	21105
24	2706	5633	10804	14252	15651	17323	20729
34	2814	5845	11078	14577	16186	17693	20763
100	2762	5768	10969	14725	16225	17893	20687
35	2670	5650	10674	14486	16090	17556	20807
141	2571	5527	10680	14245	15771	17371	---
26	2730	5687	10799	14386	15954	17442	20880
132	2679	5753	11025	14926	16384	17716	21212
149	2749	5680	10972	14617	15880	17522	21030
151	2719	5750	11002	14550	16158	17764	19652
123	2640	5501	10647	13965	15406	17548	---
3	2685	5703	10826	14556	15920	17105	21952
84	2816	5843	11200	14770	16450	17570	22210
22	2574	5572	10740	14484	16101	17532	22214
152	2781	5804	11076	14327	16062	17358	20620
No. of Samples	20	20	20	20	20	20	18
Unbiased: Mean	2704	5693	10917	14556	16072	17522	20818
Std Dev	71	102	157	234	279	237	744
NOTE: All frequencies in Hertz.							

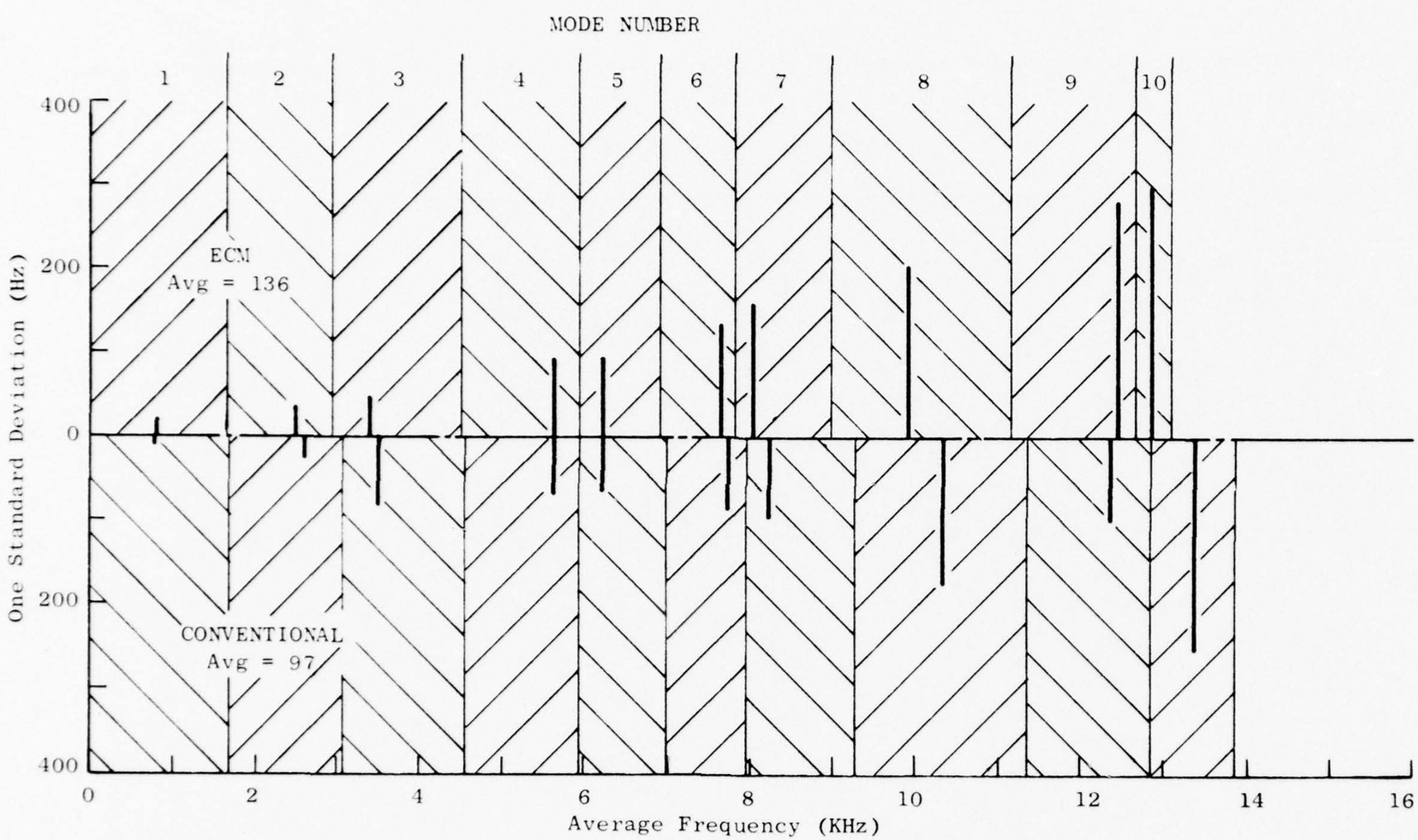


Figure 5. Resonant Frequency Summary, Stage 2 (Part No. 4013148-502P01), Standard Deviation Versus Average Frequency.

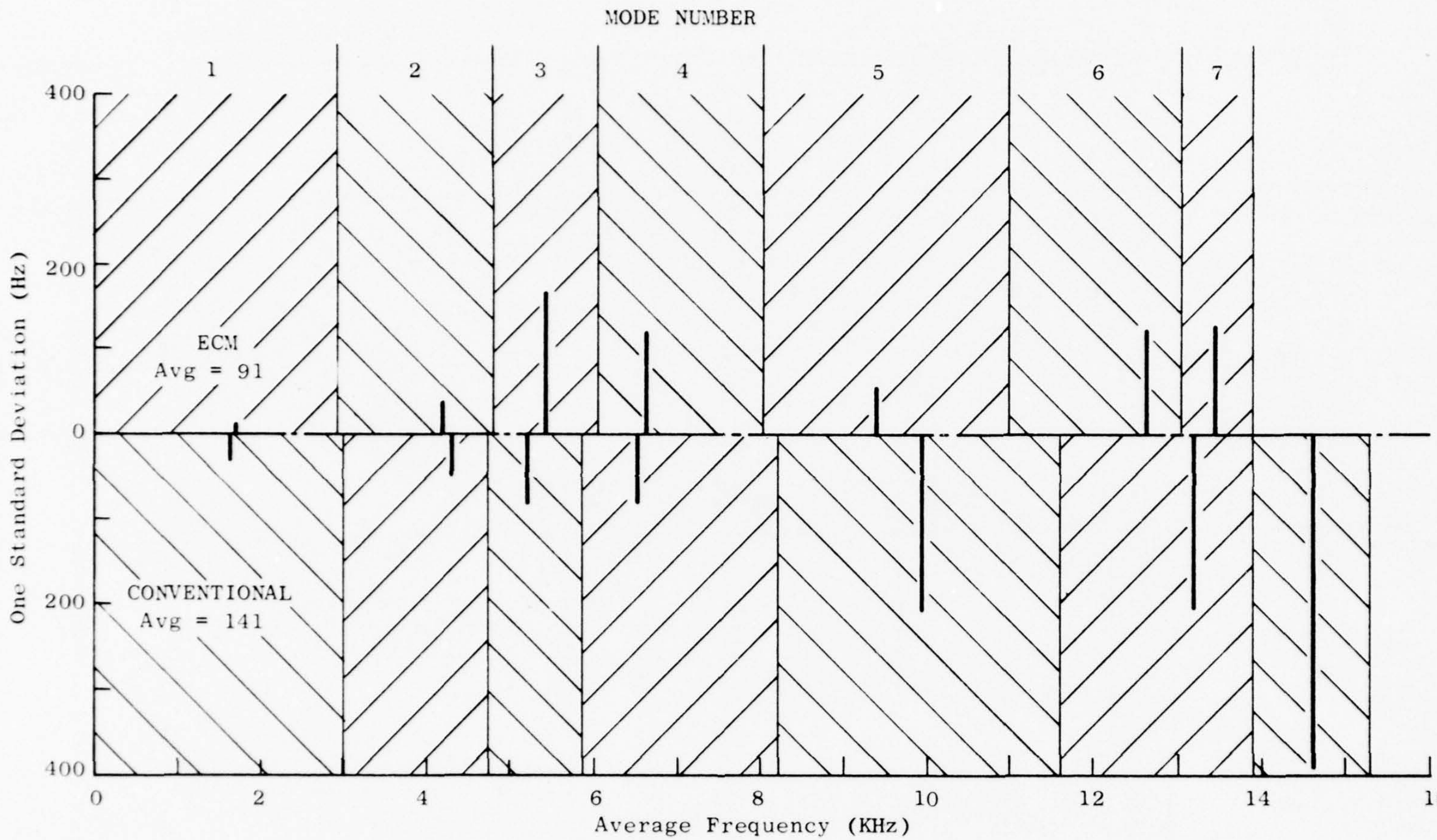


Figure 6. Resonant Frequency Summary, Stage 5 (Part No. 4013148-505P01), Standard Deviation Versus Average Frequency.

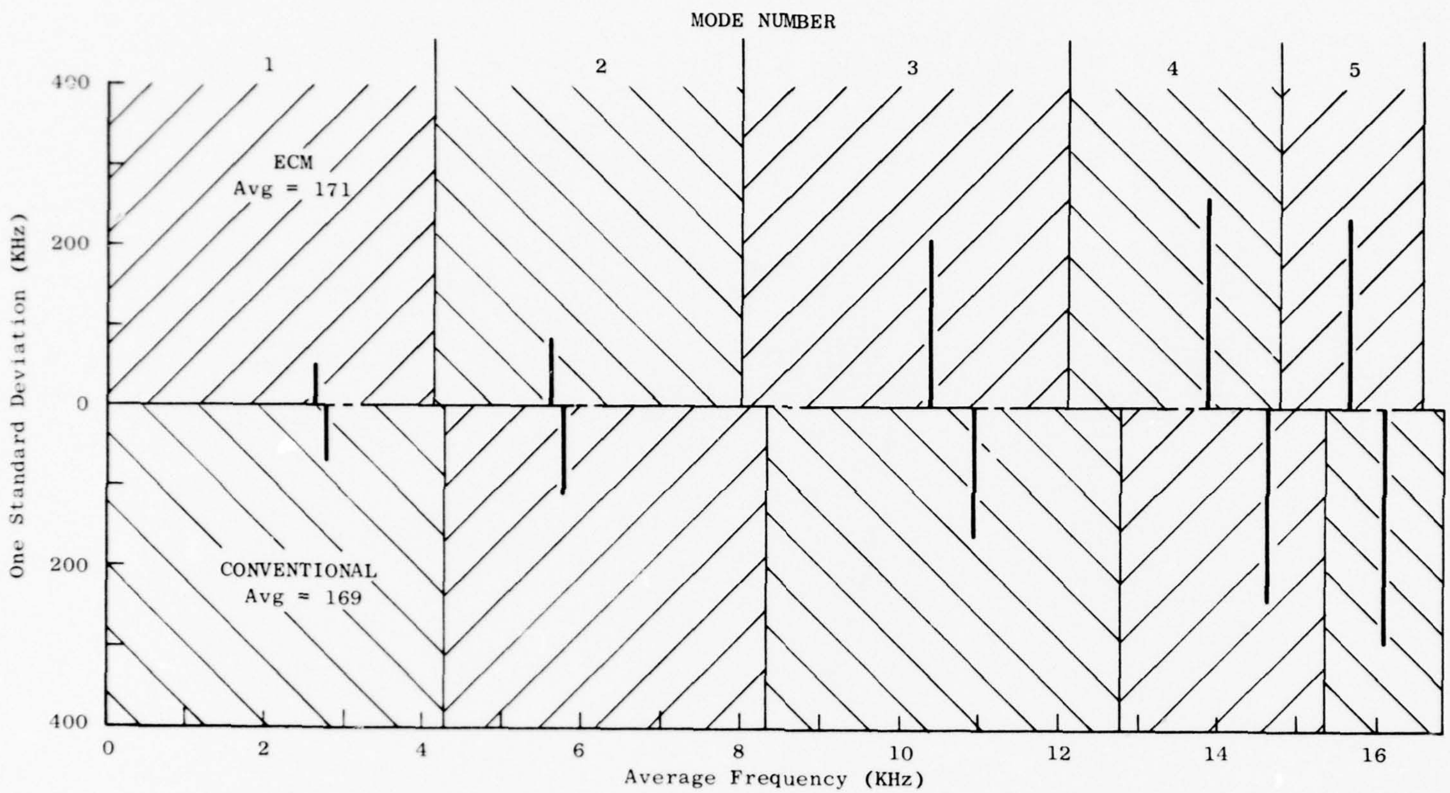


Figure 7. Resonant Frequency Summary, Stage 8 (Part No. 4013148-508P01), Standard Deviation Versus Average Frequency.

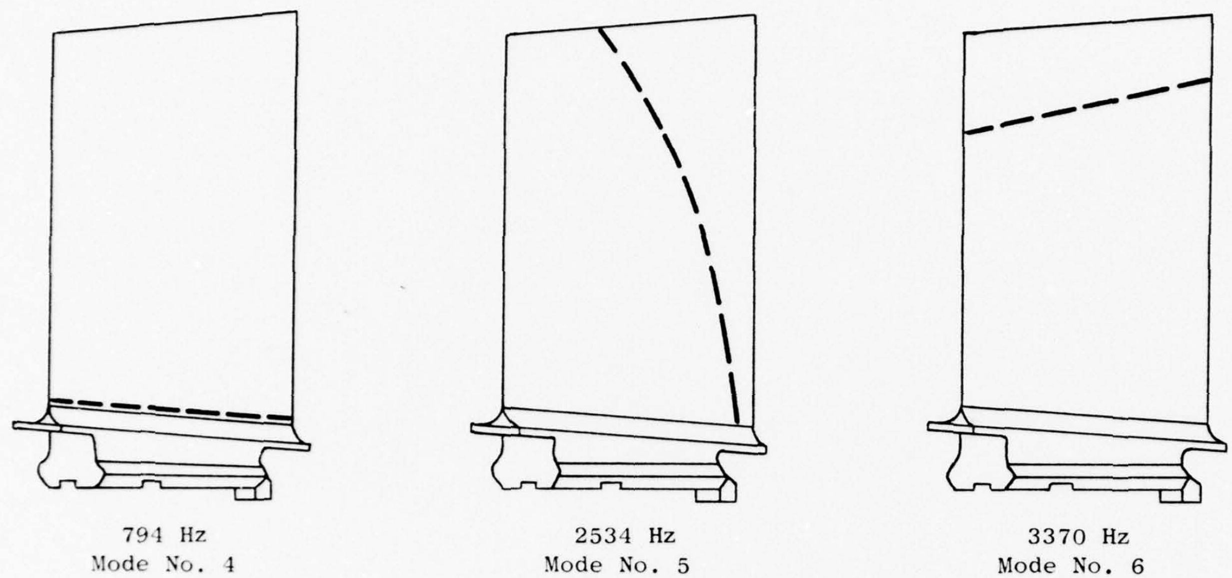
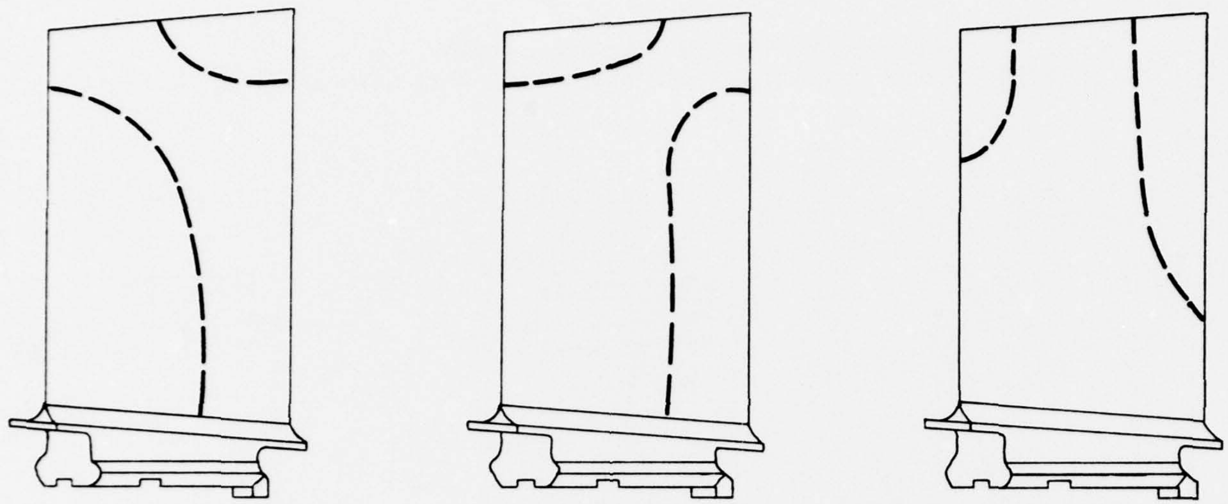


Figure 8. Resonant Frequencies and Nodal Patterns, Stage 2 Blade (Part No. 4013148-502P01), ECM Airfoil S/N 367.

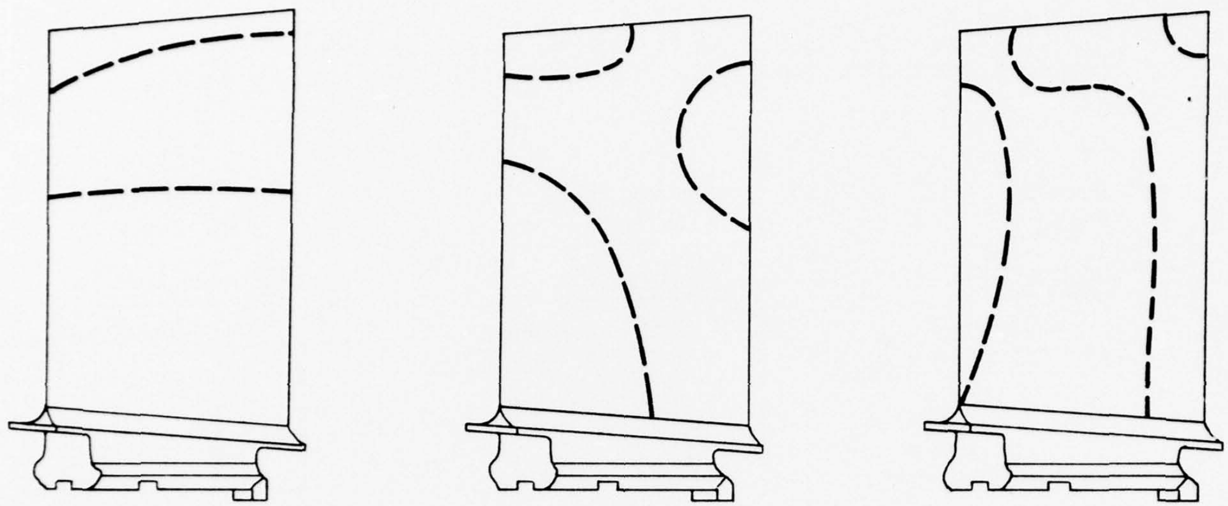


5554 Hz
Mode No. 4

6320 Hz
Mode No. 5

7480 Hz
Mode No. 6

Figure 9. Resonant Frequencies and Nodal Patterns, Stage 2 Blade (Part No. 4013148-502P01), ECM Airfoil S/N 367.

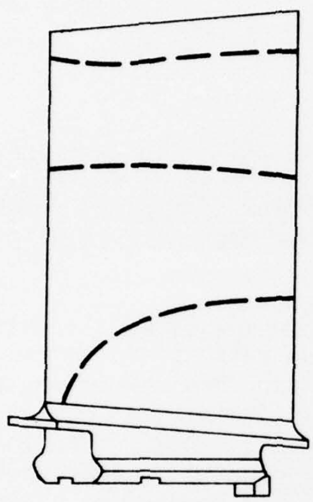


7916 Hz
Mode No. 7

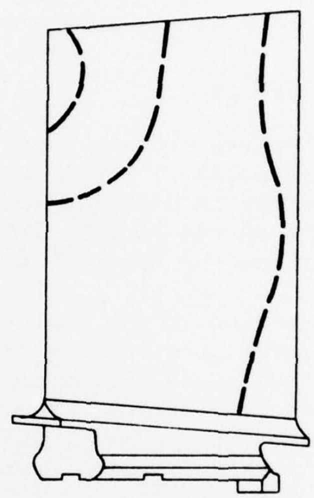
9849 Hz
Mode No. 8

12,034 Hz
Mode No. 9

Figure 10. Resonant Frequencies and Nodal Patterns, Stage 2 Blade (Part No. 4013148-502P01), ECM Airfoil S/N 367.



12,714 Hz
Mode No. 10



14,359 Hz
Mode No. 11

Figure 11. Resonant Frequencies and Nodal Patterns, Stage 2 Blade (Part No. 4013148-502P01), ECM Airfoil S/N 367.

There does not appear to be a clear-cut advantage of ECM'd airfoils over airfoils produced by conventional means with regard to natural frequencies and nodal patterns. Stage 5, however, with its as-ECM's surfaces, does exhibit consistently better frequency scatter and standard deviation. The variability produced by hand rework on Stages 2 and 8 may have distorted similar results.

Location of the nodal lines, which relates to strain distribution, did not show more consistency in one type than in the other.

C. Fatigue Results

One quarter set of each stage and manufacturer (the same ones used for frequencies and nodal patterns) were failed in the first flexural mode. Parts were clamped in fixtures to simulate engine fixity and driven in resonance using an air siren. Reference strain gages were applied to the parts to determine the level of stress.

The standard staircase fatigue test method was used. In this procedure, an arbitrary level of stress is estimated that will produce failure of the part in less than 10,000,000 cycles. If failure does not occur, the stress level is raised by a predetermined increment. The test is then conducted again on a different specimen, and the process is repeated until a failure does occur. After a failure occurs, the stress level is reduced by an increment and the test is repeated. If a failure occurs the stress is reduced for the next specimen while, if a failure does not occur the stress is increased and so on until a predetermined number of specimens is used up.

The fatigue results are presented in Figures 12 through 19. The data were analyzed using GE Specification E50TF39 entitled "Fatigue Testing - Compressor Blades and Vanes and Turbine Blades."

An advantage of ECM blades over conventional blades was found in regard to fatigue strength. The standard deviation of the ECM blades tended to be smaller than that for conventionally made blades. Hence, the average fatigue strength was diminished less for as-ECM'd blades than for conventional blades for a given design allowable strength.

Fatigue testing of the present lot of Stage 5 ECM blades showed an expectedly low fatigue strength in the unpeened condition. A comparison of blade and test specimen fatigue strength levels is contained in Table 1. Had a larger blade lot been available to provide a meaningful statistical basis, peened versus unpeened airfoils would have been tested. From test comparisons in previous studies however, a significant strength improvement resulted from peening.

This study successfully demonstrated production of high quality as-ECM R95 blades. As-peened fatigue strength comparisons between conventional machining and ECM show equal or superior values for the ECM-processed material.

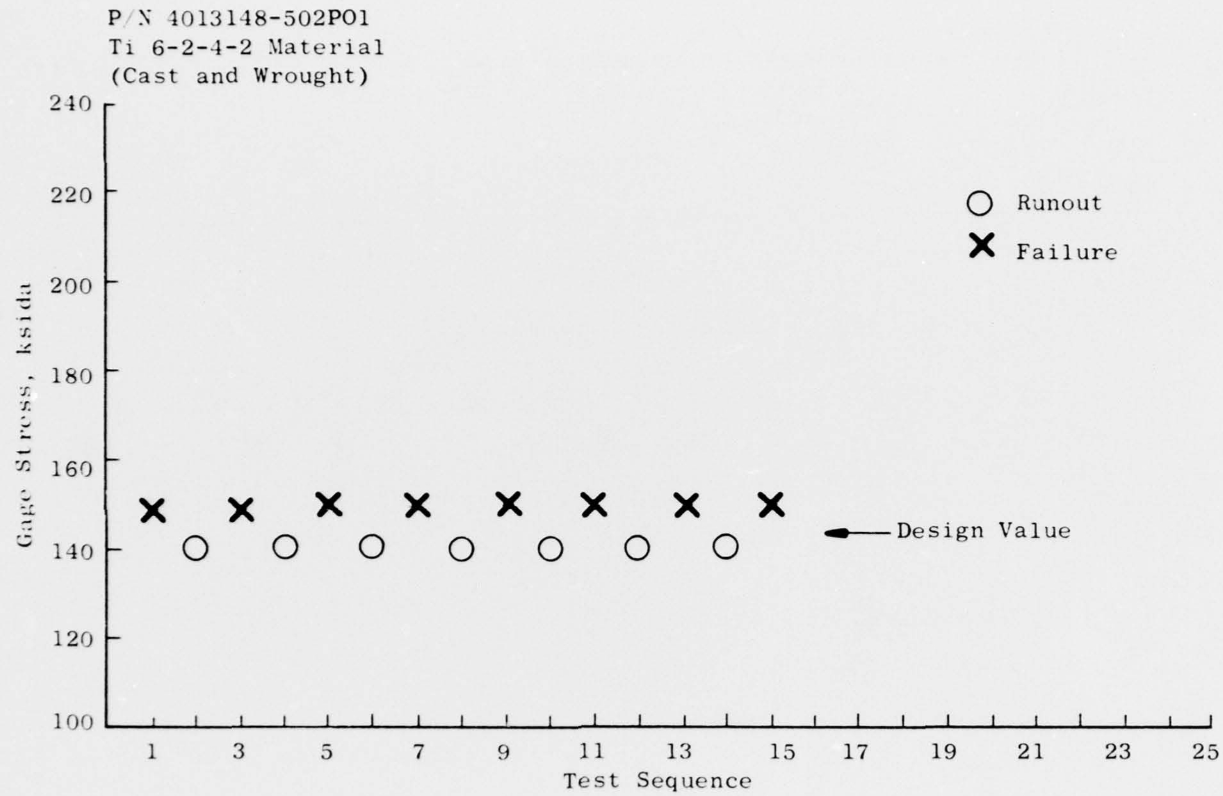


Figure 12. Fatigue Results, Stage 2 ECM Airfoil (Peened 6-10N).

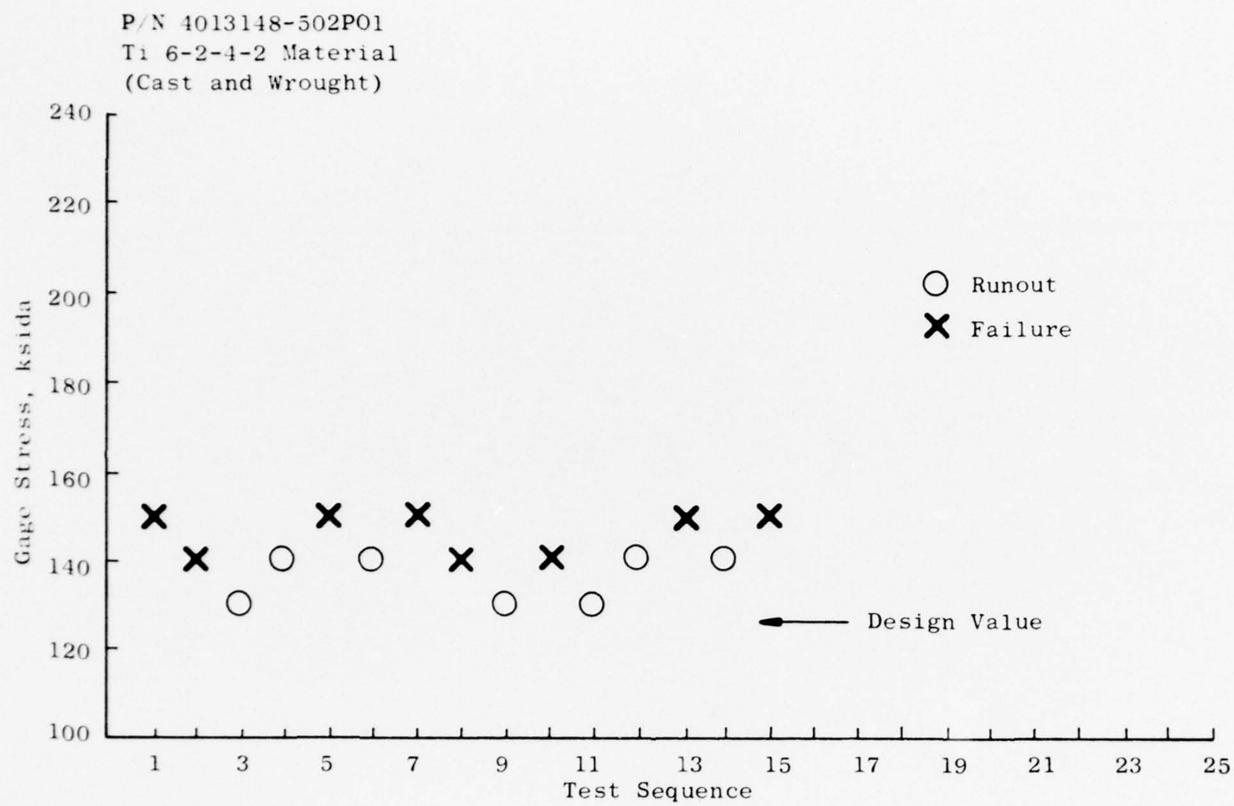


Figure 13. Fatigue Results, Stage 2 Conventional Airfoil (Peened 6-10N).

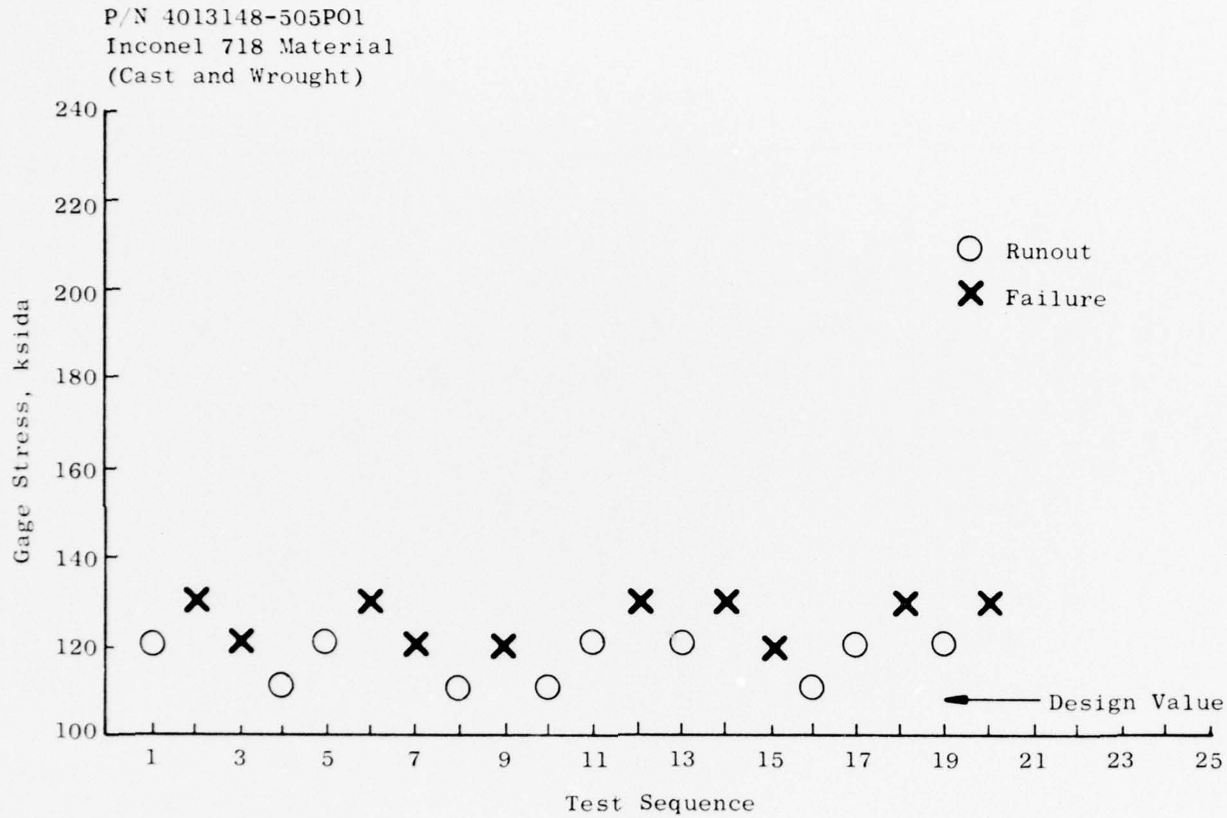


Figure 14. Fatigue Results, Stage 5 ECM Airfoil (Unpeened).

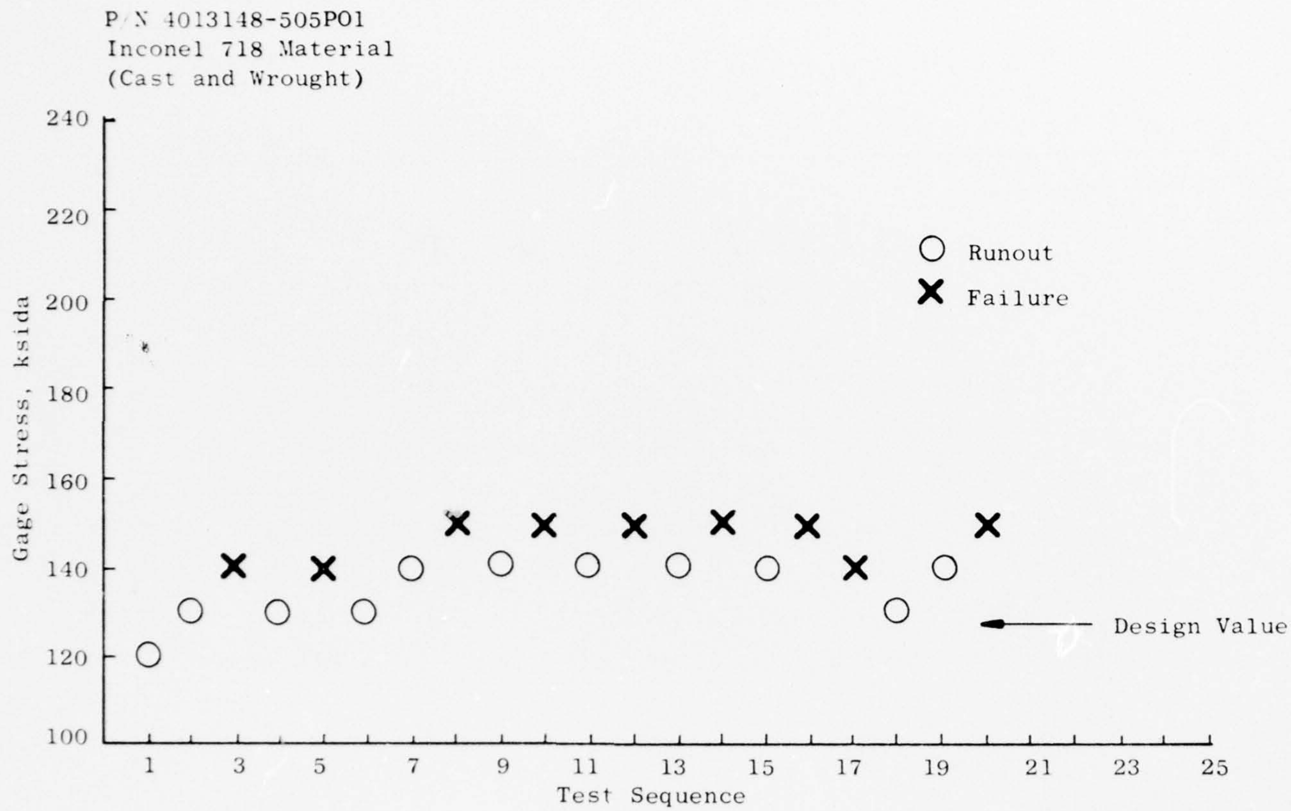


Figure 15. Fatigue Results, Stage 5 Conventional Airfoil (Peened 6-10N).

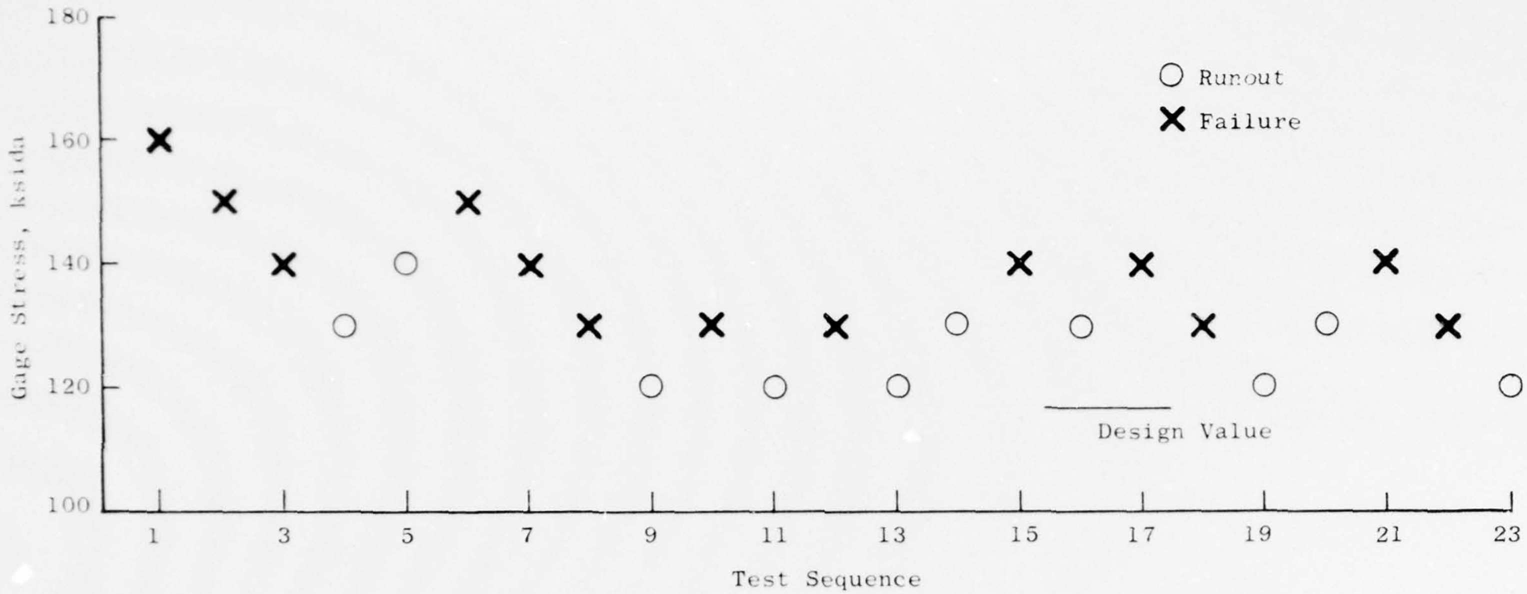


Figure 16. Fatigue Results, Stage 5 PM R95 ECM Airfoil (Unpeened).

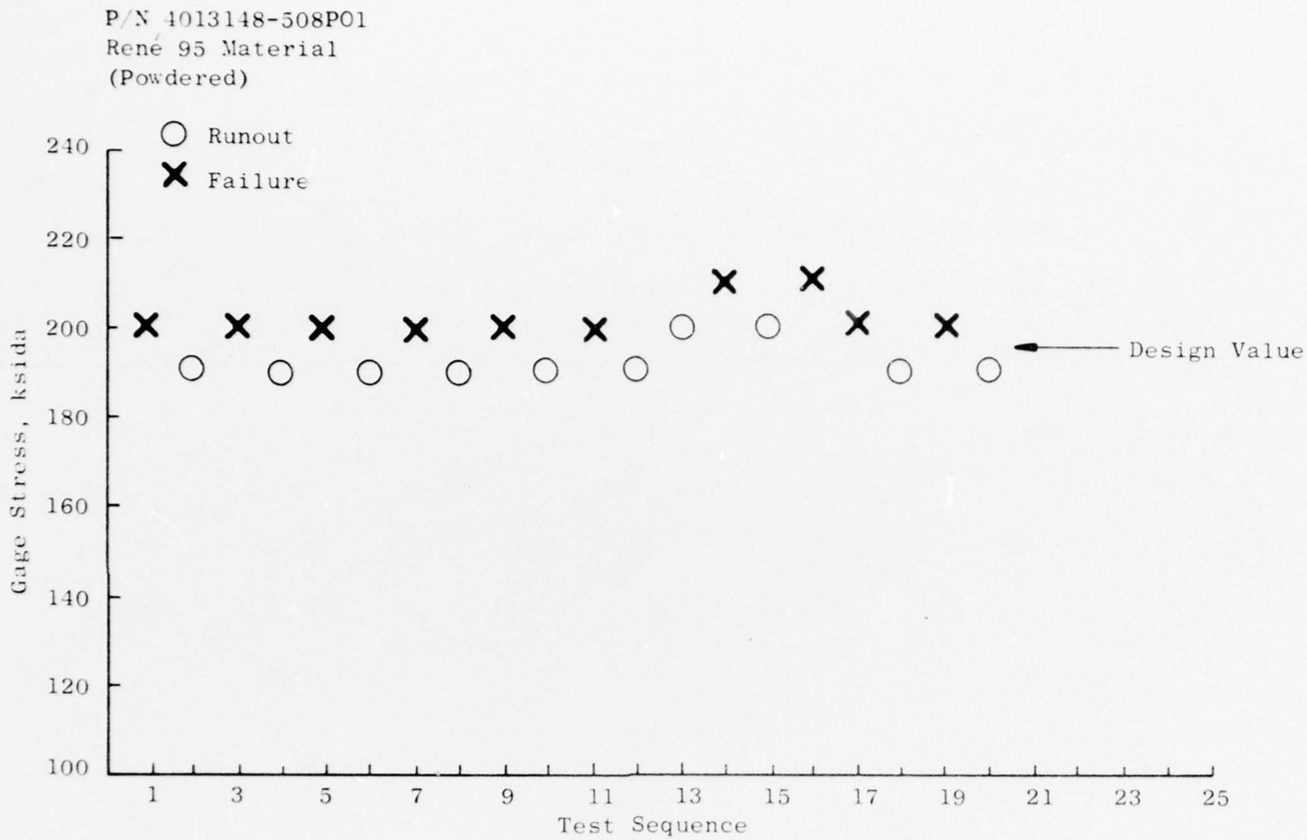


Figure 17. Fatigue Results, Stage 8 ECM Airfoil (Peened 6-10N).

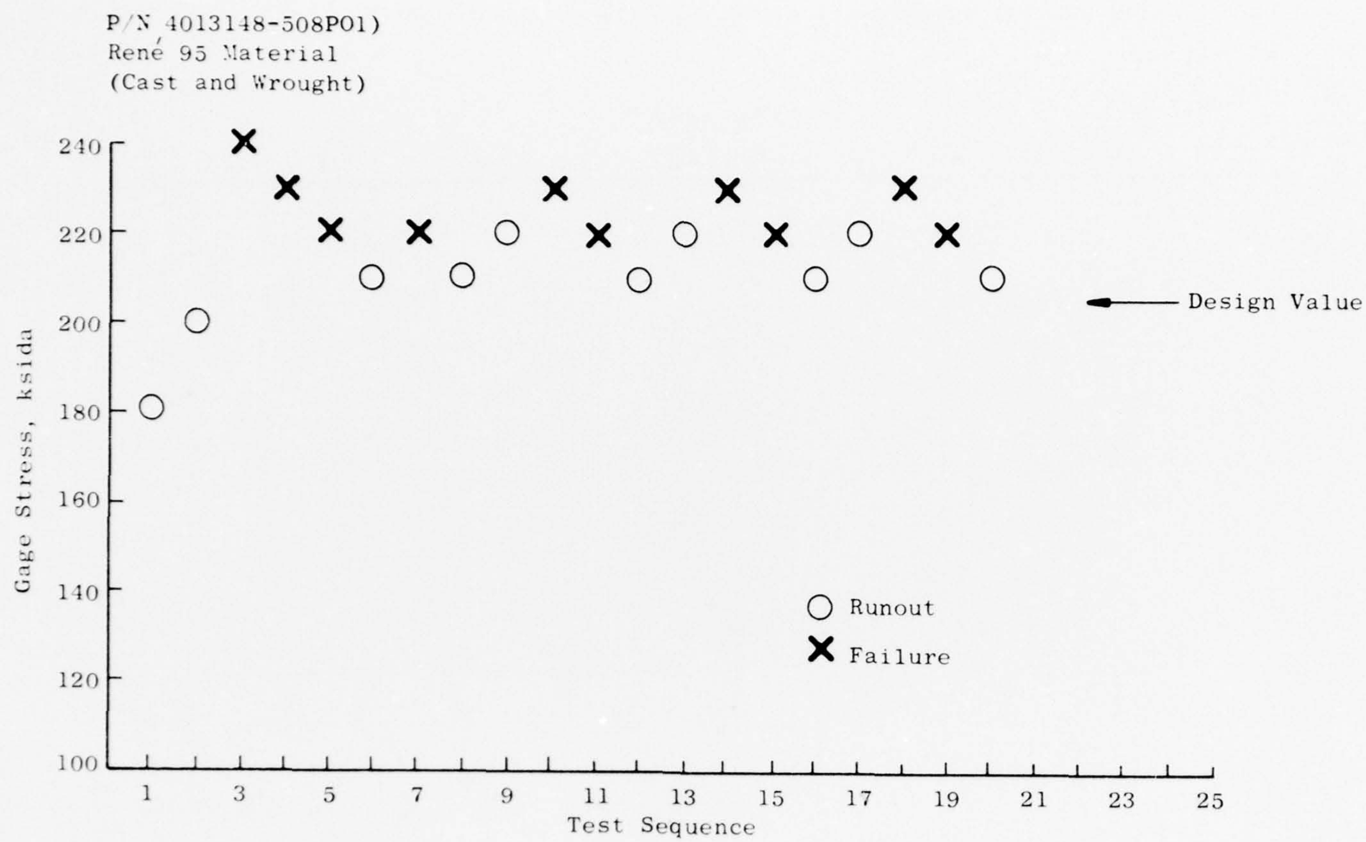


Figure 18. Fatigue Results, Stage 8 Conventional Airfoil (Peened 6-10N).

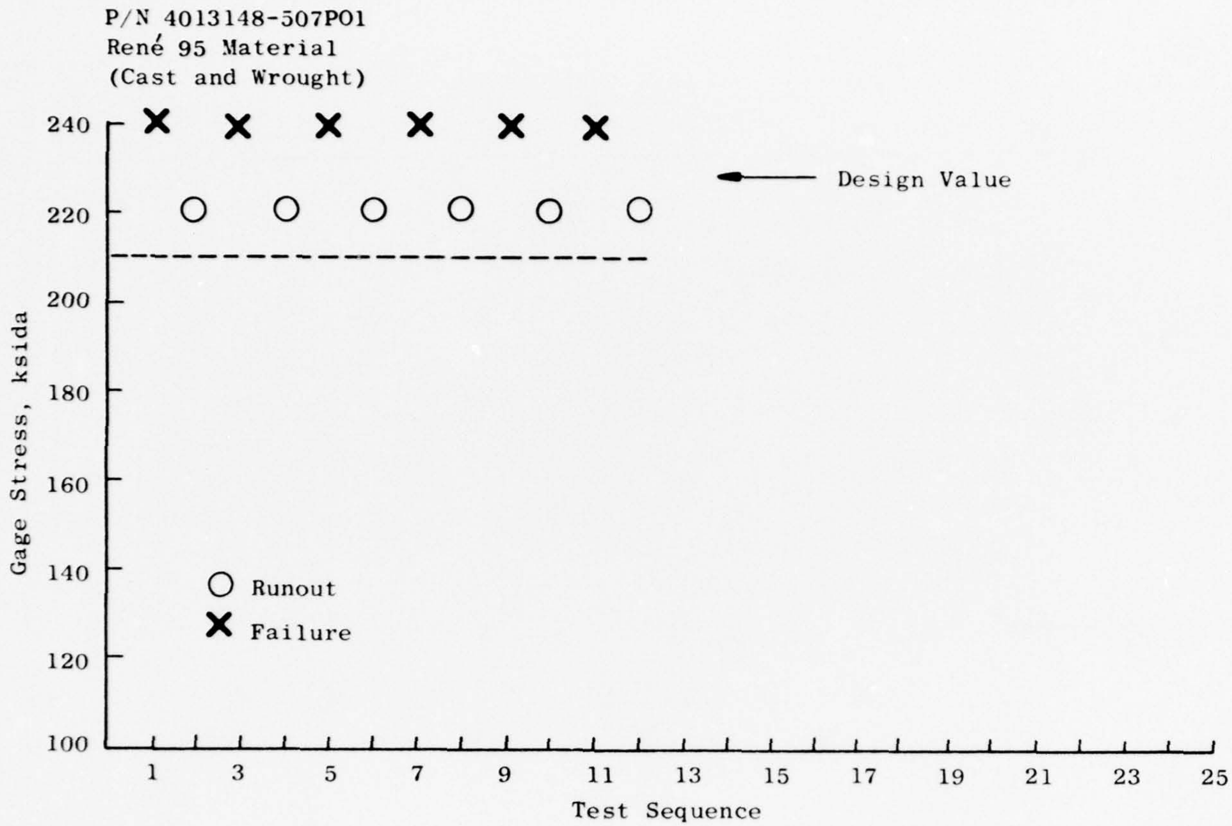


Figure 19. Fatigue Results, Stages 7 and 8 ECM Airfoil (Peened 6-10N).

The combination of good fatigue strength, dimensional and contour consistency and projected unit cost make the ECM blade production technique attractive for production of high strength nickel base alloy blades.

Estimates of the effects on compressor efficiency of the improved surface finish for all stages of a typical advanced compressor yield an improvement of 0.55%. The thicker hubs decrease this improvement by 0.1% yielding a net improvement in compressor efficiency of 0.45%.

AS-HIP'd powder metal (PM) René 95 does not have the base fatigue strength of cast and wrought material, as is evident from the lower strength of the René 95 stage 8 blades in Figure 17. A previous study produced ECM blades for Stage 8 using René 95 cast and wrought material; partial results from this prior study are presented in Figure 19, where fatigue strength is higher than that of the conventional blades (Figure 18). To this comparison must be added the knowledge that the cast and wrought René 95 used was better than the minimum specification and that the PM René 95 process is still being refined. The achievement of equal material strength is important, since René 95 blades are economical only if PM preforms can be made.

SECTION V

PROCESS STATUS

No attempt was made during the major part of the ECM study to optimize the manufacturing sequence to be cost effective. The program concentrated on the production of a high quality airfoil and, therefore, machined the dovetail last because of concern that the completed dovetail would be damaged when it carried the high current involved in the ECM generation of the airfoil. The first phase successfully produced high quality airfoils in three different sizes and materials as is evident from the results presented in Section IV "Testing and Inspection". The airfoil-making part of the ECM process was well in hand for a production-oriented process.

From the experience of the first phase of work it was apparent that the processing sequence needed to be changed to make the ECM manufacture process cost competitive for high temperature materials. Five items were noted as areas requiring improvement:

1) Quality of raw material

2) Machining of blanks to prepare for ECM

3) The removal of excess material below the platform

4) The finish machining of the dovetail pressure face

5) The need to complete all machining of the dovetail and platform underside prior to generation of the airfoil to free the airfoil of fatigue stresses induced while holding the airfoil to machine the dovetail in the original process.

A review was made of these five items and the first four were believed within current state-of-the art capability for high production manufacturing and, therefore, not in need of further study. The fifth item presented a specific problem involved with the limited dovetail shank size available. Further, problems of reliably sealing a charged electrode during the ECM process from the shank area were believed to provide a further barrier.

Difficulty with the powder metal material involved in the stage 8 ECM blades left the program technically successful but with a shortfall of 42 blades. The funding involved in the Stage 8 blade shortfall was diverted to the task of removing questions about the manufacturing sequence by producing a lot of approximately 30 Stage-5 blades using the remaining R95 material. This lot of blades would be made dovetail first.

The work of producing a lot of 30 airfoils was to be done at Lehr Precision, the vendor where the Stage 5 blades were made by ECM from Inconel 718 material during the original phase of the program. Several approaches

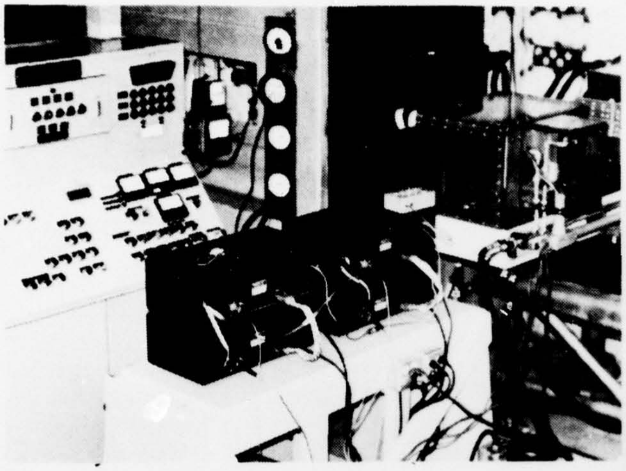
were studied for the dovetail-first manufacture process. A metal matrix cast around the finished dovetail provided a piece for the ECM process which directly resembled the blank before the dovetail was machined. This arrangement isolated the dovetail from the charged electrolyte and provided a sufficient cross section for the high current of the ECM blade processing. The arrangement also provided reliable fixturing surfaces for both the ECM process and the subsequent grinding operations which were needed to finish the four sides of the blade platform.

The equipment involved is illustrated in Figure 20. The details of the dovetail-first manufacture process were developed during a four blade pilot run and were then successfully applied to produce a lot of twenty-six high quality Stage 5 airfoils.

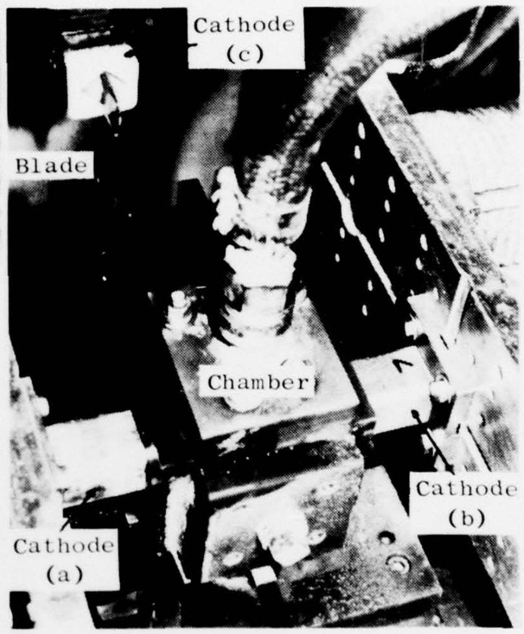
As a result of the work accomplished on the final phase of the program, it was concluded that ECM Blades can be produced with a high level of consistency of the product when compared to the present experience in conventional blade machining techniques. The end product has only the material variance and process tolerance effect to consider in blade life predictions, since there is no physical work applied to the material in the process and the end product is unaffected by the variations of tool and abrasive benching abuses inherent in conventional blade manufacture.

With proper process considerations, an ECM produced blade was judged cost competitive with a conventionally machined blade. It was estimated that, with such materials as R95, the ECM blade could be produced for the same price as an Inconel 718 blade. Blades made by conventional machining were estimated to cost nearly twice as much as Inconel 718 blades.

View of Controls
for ECM Equipment



Closeup of Partically Completed
Blade in ECM Setup



(a), (b) and (c)
are the Three
Moving Electrodes

Stage 5 R95 Blade At Various
Points in the ECM Process

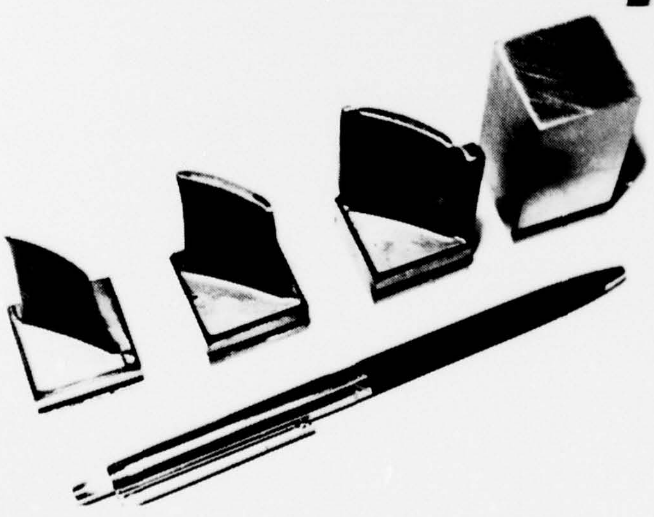


Figure 20. ECM Final Process.